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US Army Corps of Engineers

MODEL STUDY OF SHORELINE EROSION AND BEACH PROTECTION SCHEMES AT SURFSIDE-SUNSET BEACH, LONG BEACH, CALIFORNIA

Coastal Model Investigation

by

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A 1:75 scale (undistorted) hydraulic model was used to investigate the design of proposed modifications at Surfside-Sunset Beach, California, with regard to the reduction of beach erosion at the site. The model reproduced approximately 4,600 ft of the California shoreline and included the Anaheim Bay East Jetty and offshore bathymetry in San Pedro Bay to a depth of 26 ft. Proposed improvements consisted of offshore breakwaters and a breakwater attached to the existing jetty extending in a beach-parallel direction. Waves were generated by an 80-ft-long unidirectional, spectral wave generator, and a crushed coal tracer material was used to qualitatively determine the movement of beach-fill material. It was concluded from test results that:

a. Preliminary tests indicated sediment movement at Surfside-Sunset Beach to the northwest for test waves from south and south-southwest, and movement to the southeast for test waves from southwest and west-southwest.

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b. Verification tests at Surfside-Sunset Beach, based on durations of waves from various directions for hindcast data, revealed erosion of the shoreline adjacent to the Anaheim Bay East Jetty and a net movement of sediment material to the southeast and offshore similar to that observed in the prototype.

c. Test results for the 300-ft-long offshore breakwater (elevation (el) +5 ft) of Plan 1 indicated the structure was ineffective in reducing erosion of the shoreline for the +7.0 ft still-water level (swl). For the 0.0 ft swl, however, it appeared to be more effective for the limited tests conducted.

d. Test results for the 1,200-ft-long jetty attached breakwater (el -6 ft) of Plan 2 indicated the structure was effective in reducing the rate of erosion of the shoreline adjacent to the Anaheim Bay East Jetty for the +3.0 ft swl.

e. Test results for the 600-ft-long offshore breakwater (el 0.0 ft) of Plan 3 indicated the structure was ineffective in reducing erosion of the shoreline for the +3.0 ft swl.

f. Observations during conduct of the study indicated very rapid initial erosion of the sand fill in the vicinity of the Anaheim Bay East Jetty. Erosion continued, but at a decreased rate, as the shoreline reached an equilibrium profile for the conditions tested. Test results also revealed that erosion will occur more rapidly for the higher water levels.

PREFACE

A request for a model investigation for shoreline stabilization at Surfside-Sunset Beach, Long Beach, California, was initiated by the US Army Engineer District, Los Angeles (SPL), in a letter to the US Army Engineer Division, South Pacific (SPD). Authorization for the US Army Engineer Waterways Experiment Station (WES) to perform the study was subsequently granted by Headquarters, US Army Corps of Engineers. Funds were authorized by SPD on 10 August 1989.

Model testing was conducted at WES during the period December 1989-May 1990 by personnel of the Wave Processes Branch (WPB) of the Wave Dynamics Division (WDD), Coastal Engineering Research Center (CERC), under the direction of Dr. James R. Houston, Chief of CERC; Mr. Charles C. Calhoun, Jr., Assistant Chief of CERC; Mr. C. E. Chatham, Jr., Chief of WDD; and Mr. Dennis G. Markle, Acting Chief of WPB. The tests were conducted by Messrs. Hugh F. Acuff, Jr., WPB, and Mr. William G. Henderson, Instrumentation Services Division, under the supervision of Mr. Robert R. Bottin, Jr., Project Manager, WPB. This report was prepared by Messrs. Bottin and Acuff and typed by Ms. Debbie S. Fulcher, WPB.

During the course of the investigation, Mr. Bottin visited Long Beach, California, to inspect the prototype site, and Messrs. Art J. Shak and Dave R. Patterson of SPL visited WES to observe model operation and participate in conferences. Liaison was maintained by means of conferences, telephone communications, and periodic progress reports.

COL Larry B. Fulton, EN, was Commander and Director of WES during the conduct of this investigation and the preparation and publication of this report. Dr. Robert W. Whalin was Technical Director.

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CONVERSION FACTORS, NON-SI TO SI (METRIC)
UNITS OF MEASUREMENT

Non-SI units of measurement used in this report can be converted to SI (metric) units as follows:

Multiply	By	To Obtain
cubic yards	0.7646	cubic metres
degrees (angle)	0.01745329	radians
feet	0.3048	metres
inches	25.4	millimetres
miles (U.S. statute)	1.609344	kilometres
pounds (force)	4.4482224	newtons
square feet	0.09290304	square metres
square miles (U.S. statute)	2.589988	square kilometres
tons (2,000 lb, force)	8896.444	kilonewtons

MODEL STUDY OF SHORELINE EROSION AND BEACH PROTECTION SCHEMES AT SURFSIDE-SUNSET BEACH, LONG BEACH, CALIFORNIA

Coastal Model Investigation

PART I: INTRODUCTION

The Prototype

1. Surfside-Sunset Beach is located in Long Beach, California, along the upper-coastline of Orange County immediately southeast of Anaheim Bay (Figure 1). Beach erosion downcoast of the Anaheim Bay East Jetty has been a serious and continuing problem, requiring the placement of large volumes of replenishment sand. Over the last 45 years an average of 360,000 cu yd* of sand (Tekmarine 1989) has been placed on the beach per year, and approximately the same quantity, on the average, has left the study region. The U.S. Army Corps of Engineers replenishes Surfside-Sunset Beach, about every five years. The cost of beach nourishment is cost-shared between the Federal government, the State of California, and local governments.

2. During the period 1964-1984, approximately 11,000,000 cu yd of sand was placed at Surfside-Sunset Beach (Patterson 1990). It has served as a feeder beach for the downcoast littoral cell. The direction of net longshore transport in this Surfside-Sunset Beach area is considered by most researchers to be southerly (Patterson 1990). Some of the material, however, is believed to be transported offshore. The Surfside-Sunset Beach shoreline is shown in Figure 2.

Purpose of the Model Study

3. The US Army Engineer District, Los Angeles (SPL) is performing an "Alternative Structures Study" to determine if structural improvements at Surfside-Sunset Beach could be used to reduce future beach replenishment construction costs. Potential cost savings may be realized if the current

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* A table of factors for converting Non-SI units of measurement to SI (metric) units is presented on page 3.

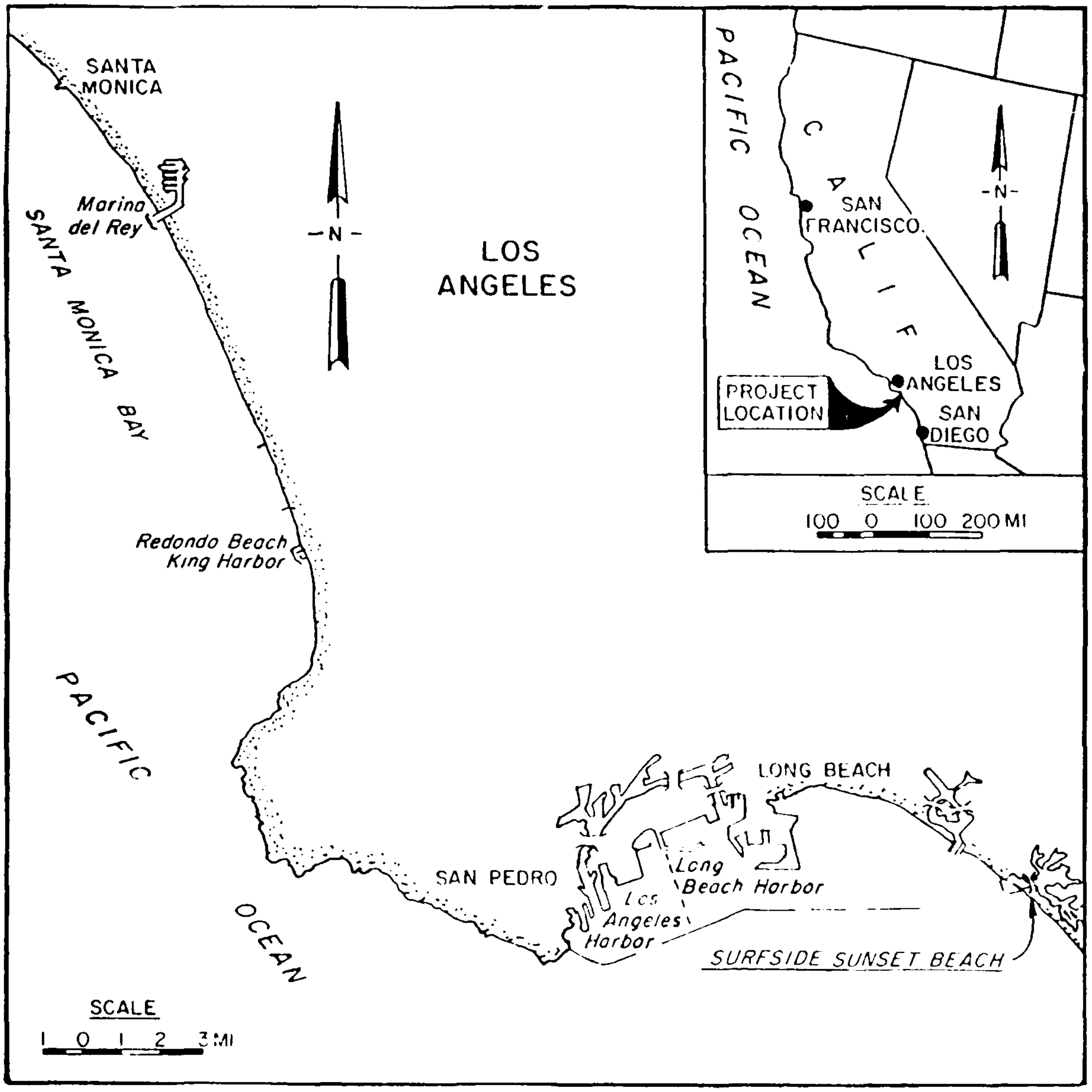

Figure 1. Project location

Figure 2. Shoreline southeast of Anaheim Bay East Jetty

interval of five years between beach-fill construction can be extended and/or if beach-fill quantities can be reduced. In support of this study, SPL requested that the US Army Engineer Waterways Experiment Station's (WES) Coastal Engineering Research Center (CERC) perform a qualitative sediment transport model study to examine existing conditions and the relative performance of three structural alternatives. The scope included:

<u>a</u>. Study qualitative sediment movement patterns at the site by determining the response of the shoreline to waves from various directions.

<u>b</u>. Verify erosion of the sandfill using wave durations from various directions, as defined by hindcast data, to verify performance of the model.

<u>c</u>. Evaluate the relative performance of three improvement plans with regard to their effectiveness in reducing erosion and providing a more stable shoreline at the site.

Proposed Improvements

4. Plans selected for testing in the model include: (a) a 300-ft-long offshore breakwater with a +5 ft crest el**, (b) a 1,200-ft-long breakwater with a -6 ft crest el connected to the Anaheim Bay jetty, and (c) a 600-ft-long offshore breakwater with a 0.0 ft crest el.

** All elevations (el) cited herein are in feet referred to mean lower low water (mllw).

PART II: THE MODEL

Design of Model

5. The Surfside-Sunset Beach model contours were constructed on an existing model of Bolsa Chica, California (Bottin and Acuff 1989), which is located adjacent to and south of the site. This approach was used due to limited funds for the project. The Surfside-Sunset model contours relative to the Bolsa Chica model are shown in Figure 3. The model was constructed to an undistorted linear scale of 1:75, model to prototype. Scale selection was based on such factors as:

- a. Depth of water required in the model to prevent excessive bottom friction.
- b. Absolute size of model waves.
- c. Available shelter dimensions and area required for model construction.
- d. Efficiency of model operation.
- e. Available wave-generating and wave-measuring equipment.
- f. Model construction costs.

A geometrically undistorted model was necessary to ensure accurate reproduction of wave and current patterns. Following selection of the linear scale, the model was designed and operated in accordance with Froude's model law (Stevens, et al., 1942). The scale relations used for design and operation of the model were as follows:

Characteristic	Dimension*	Model-Prototype Scale Relations
Length	L	$L_r = 1:75$
Area	L^2	$A_r = L_r^2 = 1:5,625$
Volume	L^3	$V_r = L_r^3 = 1:421,875$
Time	T	$T_r = L_r^{1/2} = 1:8.66$
Velocity	L/T	$V_r = L_r^{1/2} = 1:8.66$

* Dimensions are in terms of length (L) and time (T).

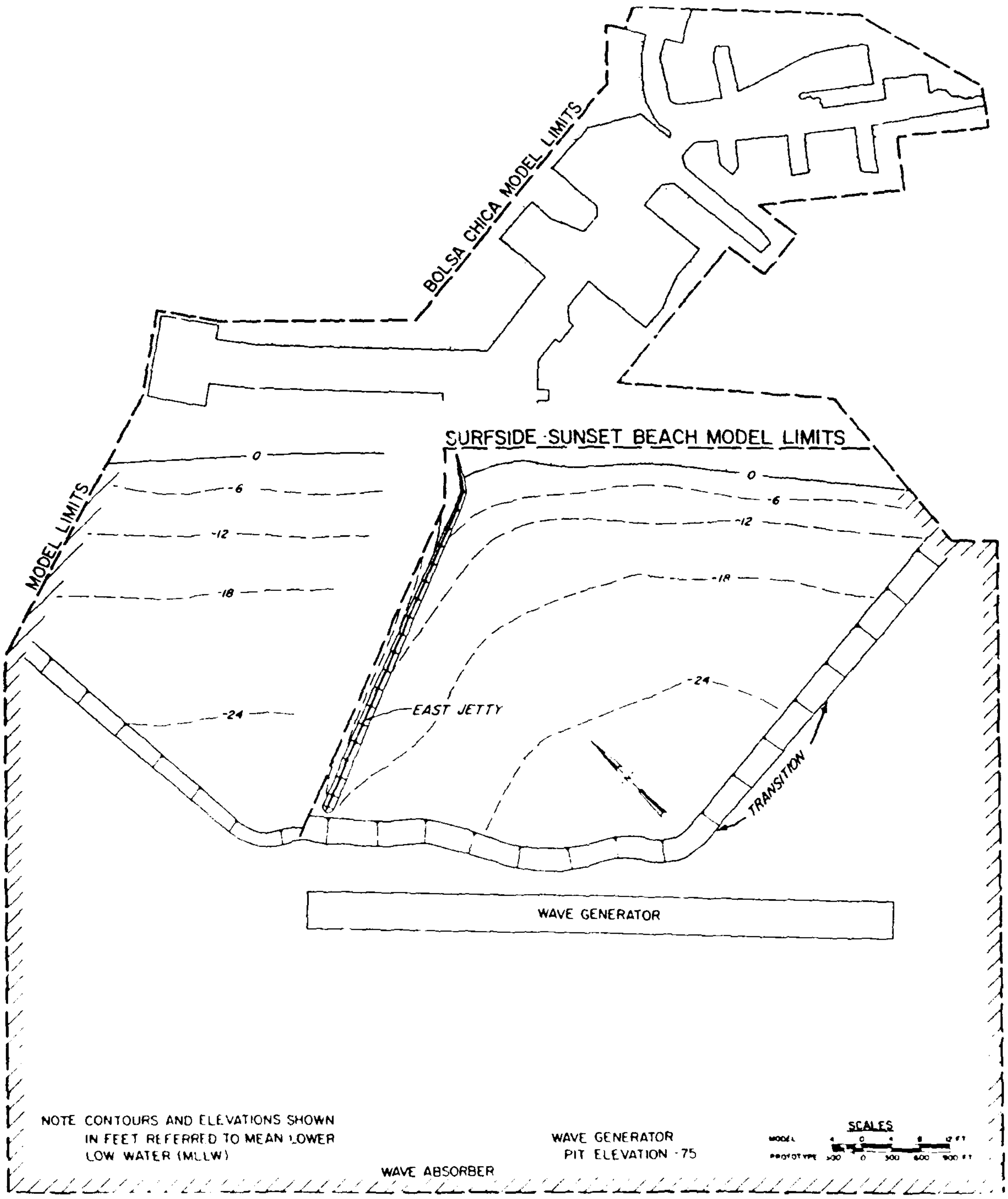

Figure 3. Surfside-Sunset Beach model contours relative to the Bolsa Chica model

6. The existing jetty at Anaheim Bay, as well as proposed improvements at Surfside-Sunset Beach, included the use of rubble-mound structures. Experience and experimental research have shown that considerable wave energy passes through the interstices of this type structure; thus, the transmission

and absorption of wave energy became a matter of concern in design of the 1:75-scale model. In small-scale hydraulic models, rubble-mound structures reflect relatively more and absorb or dissipate relatively less wave energy than geometrically similar prototype structures (Le Méhauté 1965). Also, the transmission of wave energy through a rubble-mound structure is relatively less for the small-scale model than for the prototype. Consequently, some adjustment in small-scale model rubble-mound structures is needed to ensure satisfactory reproduction of wave-reflection and wave-transmission characteristics. In past investigations (Dai and Jackson 1966, Brasfeild and Ball 1967) at WES, this adjustment was made by determining the wave-energy transmission characteristics of the proposed structure in a two-dimensional model using a scale large enough to ensure negligible scale effects. A section then was developed for the small-scale, three-dimensional model that would provide essentially the same relative transmission of wave energy. Therefore, from previous findings for structures and wave conditions similar to those at Surfside-Sunset Beach, it was determined that a close approximation of the correct wave-energy transmission characteristics could be obtained by increasing the size of the rock used in the 1:75-scale model to approximately one-and-one-half times that required for geometric similarity. Accordingly, in constructing the rubble-mound structures in the Surfside-Sunset Beach model, the rock sizes were computed linearly by scale, then multiplied by 1.5 to determine the actual sizes to be used in the model.

7. A fixed-bed model, molded in cement mortar, and a coal tracer material was used to qualitatively determine sediment patterns along the beach for existing conditions and various improvement plans. This approach was recently used in a model of Buhne Point, Humboldt Bay, California, (Bottin and Earickson 1984). Structures recommended in the model have subsequently been installed in the prototype at Buhne Point resulting in a stable shoreline and successful beach restoration project (Bottin 1990).

The Model and Appurtenances

8. The model reproduced about 4,600 ft of the California shoreline and included the Anaheim Bay East Jetty and underwater topography in San Pedro Bay to an offshore depth of -26 ft with a sloping transition to the wave generator pit el of -75 ft. The total area reproduced in the model was 13,000 sq ft,

representing about 2.6 sq miles in the prototype. A general view of the model is shown in Figure 4. Vertical control for model construction was based on mean lower low water (mllw). Horizontal control was referenced to a local prototype grid system.

9. Model waves were generated by an 80-ft-long, unidirectional spectral, electrohydraulic, wave generator with a trapezoidal-shaped, vertical-motion plunger. The wave generator used a hydraulic power supply. The vertical motion of the plunger was controlled by a computer-generated command signal, and the movement of the plunger caused a periodic displacement of water which generated the required test waves. The wave generator also was mounted on retractable casters which enabled it to be positioned to generate waves from the required directions. An automated data acquisition and control system, designed and constructed at WES, was used to generate and transmit control signals and monitor wave generator feedback.

Figure 4. General view of model

10. A 2-ft (horizontal) solid layer of fiber wave absorber was placed around the inside perimeter of the model to dampen any wave energy that might otherwise be reflected from the model walls. In addition, guide vanes were

placed along the wave generator sides in the flat pit area to ensure proper formation of the wave train incident to the model contours.

Selection of Tracer Material

11. As discussed in paragraph 7, a fixed-bed model was constructed and a tracer material selected to qualitatively determine the deposition of the beach fill at Surfside-Sunset. The tracer was chosen in accordance with the scaling relations of Noda (1972), which indicate a relation or model law among the four basic scale ratios, i.e. the horizontal scale, λ; the vertical scale, μ; the sediment size ratio, η_D; and the relative specific weight ratio, η_γ. These relations were determined experimentally using a wide range of wave conditions and bottom materials and are valid mainly for the breaker zone.

12. Noda's scaling relations indicate that movable-bed models with scales in the vicinity of 1:75 (model to prototype) should be distorted (i.e., they should have different horizontal and vertical scales). Since the fixed-bed model of Surfside-Sunset Beach was undistorted to allow accurate reproduction of short-period wave and current patterns, the following procedure was used to select a tracer material. Using the prototype sand characteristics (median diameter, D_{50} = 0.25 mm, specific gravity = 2.65) and assuming the horizontal scale to be in similitude (i.e. 1:75), the median diameter for a given specific gravity of tracer material and the vertical scale were computed. The vertical scale was then assumed to be in similitude and the tracer median diameter and horizontal scale was computed. This resulted in a range of tracer sizes for given specific gravities that could be used. Although several types of movable-bed tracer materials were available at WES, previous investigations (Giles and Chatham 1974, Bottin and Chatham 1975) indicated that crushed coal tracer more nearly represented the movement of prototype sand. Therefore, quantities of crushed coal (specific gravity - 1.30; median diameter, D_{50} = 0.64 mm) were selected for use as a tracer material throughout the model investigation.

PART III: TEST CONDITIONS AND PROCEDURES

Selection of Test Conditions

Still-water level

13. Still-water levels (swl's) for harbor wave action models are selected so that the various wave-induced phenomena that are dependent on water depths are accurately reproduced in the model. These phenomena include the refraction of waves in the project area, the overtopping of harbor structures by the waves, the refection of wave energy from various structures, and the transmission of wave energy through porous structures.

14. In most cases, it is desirable to select a model swl that closely approximates the higher water stages which normally occur in the prototype for the following reasons:

- a. The maximum amount of wave energy reaching a coastal area normally occurs during the higher water phase of the local tidal cycle.
- b. Most storms moving onshore are characteristically accompanied by a higher water level due to wind-induced mass transport, atmospheric pressure fluctuations, and wave set-up.
- c. The selection of a high swl helps minimize model scale effects due to viscous bottom friction.
- d. When a high swl is selected, a model investigation tends to yield more conservative results.

15. Based on a review of 63 years of tide data from a gage located in Los Angeles Harbor, the annual return interval water level at the site is +7.0 ft (U.S. Army Engineer District, Los Angeles 1988). A swl of +7.0 ft, therefore, was initially selected for use during model testing. During the course of the study, however, it was determined that a +3.0 ft swl would be more representative of average conditions at the site. A 0.0 ft swl was also used for one test plan.

Factors influencing selection of test wave characteristics

16. In planning the testing program for a model investigation of harbor wave-action problems, it is necessary to select dimensions and directions for the test waves that will allow a realistic test of proposed improvement plans and an accurate evaluation of the elements of the various proposals. Surface-

wind waves are generated primarily by the interactions between tangential stresses of wind flowing over water, resonance between the water surface and atmospheric turbulence, and interactions between individual wave components. The height and period of the maximum wave that can be generated by a given storm depend on the wind speed, the length of time that wind of a given speed continues to blow, and the water distance (fetch) over which the wind blows. Selection of test wave conditions entails evaluation of such factors as:

a. The fetch and decay distances (the latter being the distance over which waves travel after leaving the generating area) for various directions from which waves can attack the problem area.

b. The frequency of occurrence and duration of storm winds from the different directions.

c. The alignment, size, and relative geographic position of protective structures in the problem area.

d. The alignments, lengths, and locations of the various reflecting surfaces.

e. The refraction of waves caused by differentials in depth in the area seaward of the area, which may create either a concentration or a diffusion of wave energy at the site.

Wave refraction

17. When wind waves move into water of gradually decreasing depth, transformations take place in all wave characteristics except wave period (to the first order of approximation). The most important transformations with respect to the selection of test wave characteristics are the changes in wave height and direction of travel due to the phenomenon referred to as wave refraction. For regular waves, the change in wave height and direction are determined by calculating refraction coefficients (K_r) from deepwater to shallow-water, and multiplying them by the shoaling coefficient (K_s) to give conversion factors for transfer of deepwater wave heights to shallow water heights. The shoaling coefficient is a function of wave length and water depth and can be obtained from the Shore Protection Manual (1984).

18. Computations were performed in the Bolsa Chica model to determine the variation of refraction coefficients from a wave hindcast station to the approximate location of the wave generator in the model. Shoaling coefficients were computed for a depth corresponding to the simulated depth in the wave generator pit. K_r multiplied by K_s gave conversion factors for transfer of wave conditions at the selected wave hindcast station to shallow

water values (location of wave generator in the model). For the Bolsa Chica study (Bottin and Acuff 1989), refraction and shoaling coefficients and shallow-water directions were obtained for various wave periods from five directions (west counterclockwise through south) of wave approach. With the exception of wave conditions from west, the characteristics of waves at Surfside-Sunset Beach should be similar to those at Bolsa Chica, the two areas being adjacent to each other. Surfside-Sunset Beach is protected from waves from a westerly direction by the Long Beach Breakwater. Based on the refracted directions determined at the wave generator locations in the model for each wave period, the following test directions (hindcast station direction and corresponding shallow-water direction) were selected for use during model testing.

Wave Hindcast Direction deg	Shallow-Water Test Direction deg
West-Southwest, 247.5	242
Southwest, 225	225
South-Southwest, 202.5	207
South, 180	188

Prototype wave data and selection of test waves

19. Statistical wave hindcast estimates representative of this area, were developed as a wave information task (Jensen, in preparation) during the Bolsa Chica studies (Bottin and Acuff 1989). Wave estimates were developed with a numerical grid spacing of five nautical miles in San Pedro Bay. The hindcast station used for Bolsa Chica was located in a 66-ft depth, seaward of the proposed entrance. These data are summarized in Table 1. These hindcast wave estimates were converted to shallow-water values by application of refraction and shoaling coefficients and are shown in Table 2. With the exception of wave conditions from west, wave characteristics at Surfside-Sunset should be similar to those at the adjacent Bolsa Chica site.

Characteristics of waves ($H_{1/3}$ or significant wave heights) used in the Surfside-Sunset model (selected from Table 2) are shown in the following tabulation:

Direction at Hindcast Station	Selected Test Waves Period, sec	Height, ft
West-Southwest	9	9
	11	7
	13	9
	15	7
	15	15
Southwest	5	7
	11	10
	13	10
South-Southwest	7	8
	9	8
	13	8
South	5	7
	9	8

20. Unidirectional wave spectra for the selected test waves were generated (based on JONSWAP parameters), and used throughout the model investigation. Plots of typical wave spectra are shown in Figure 5. The dashed line represents the desired spectra while the solid line represents the spectra generated by the wave machine. A typical wave train time history plot is also shown in Figure 6, which depicts water surface elevation (η) versus time.

Analysis of Model Data

21. Relative merits of the various plans tested were evaluated by:

a. Comparison of tracer movement and subsequent erosion and accretion patterns.

b. Visual observations and photographs.

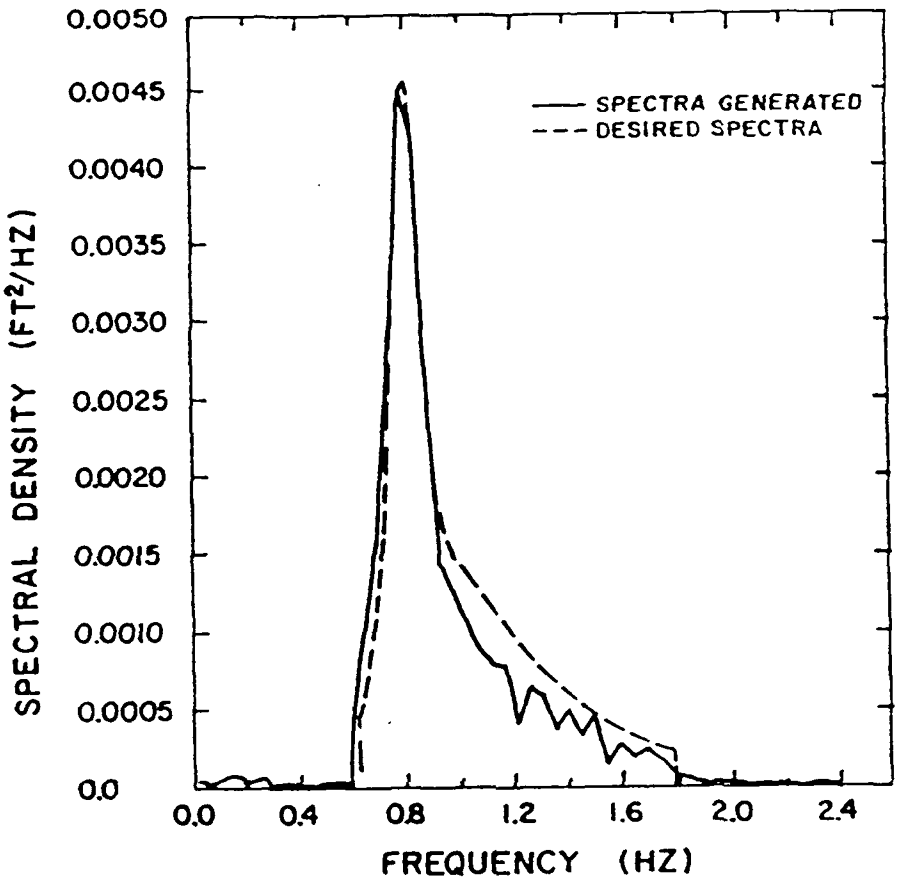

Figure 5. Typical wave-spectra plot, 11-sec, 10-ft waves

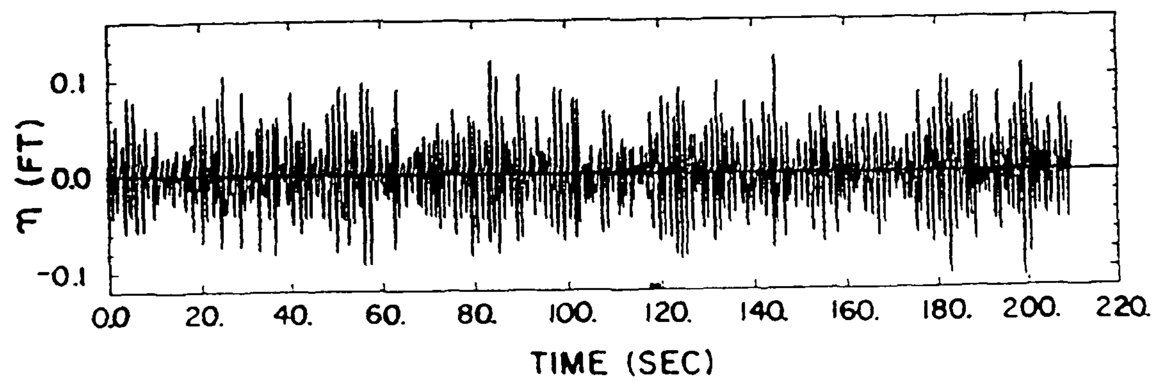

Figure 6. Typical water level time-history, 11-sec, 10-ft test waves

PART IV: TESTS AND RESULTS

The Tests

Base Tests

22. The shoreline at Surfside-Sunset Beach was constructed (fixed bed) in an eroded state, and a crushed coal tracer material was placed along the shore to represent a sandfill (as is constructed in the prototype). Prior to testing of the various improvement plans, tracer tests were conducted for base test conditions to qualitatively determine sediment patterns and causes of erosion at the site. Preliminary tests were conducted to determine the response of the shoreline to waves from various directions, and verification tests were conducted using the hindcast durations of test waves from various directions in the prototype in an attempt to verify the performance of the model. Preliminary and verification tests were conducted with a +7.0 ft swl. Additional base tests were conducted with a +3.0 ft swl to establish a base from which to evaluate the various improvement plans. Shoreline changes for base test conditions are shown in Plates 1-9. Photographs were also used to define before and after conditions for base tests.

Improvement plans

23. Model tests were conducted for three basic structural improvement plans at Surfside-Sunset Beach. Two offshore breakwaters (headlands) and a low-crested breakwater connected to the jetty, all in conjunction with the sandfill, were tested to determine their relative effectiveness in reducing coastal erosion at the site. Brief descriptions of the test plans are presented in the following subparagraphs. Layouts of the various structures, as well as shoreline changes, are shown in Plates 10-15. Photographs also were used to document shoreline conditions before and after the tests.

a. Plan 1 consisted of a 300-ft-long offshore breakwater located approximately 1,000 ft southeast of the Anaheim Bay East Jetty. The structure had a 12-ft-wide crest width with a +5 ft el, a 1V:4H slope on its sea side and a 1V:2H slope on its shore side. Armor stone weights, ranging from 7 to 15 tons were used for construction.

b. Plan 2 consisted of a low-crested breakwater (crest el -6 ft) attached to the East Jetty approximately 2,700 ft from its seaward end and extending 1,200 ft in a beach parallel direction. The structure had 1V:2H side slopes both on its seaward and shoreward sides, and a 30-ft-wide crest.

Armor stone weights ranged from 7 to 15 tons with underlayer stone ranging from 2 to 7 tons.

c. Plan 3 entailed a 600-ft-long offshore breakwater situated 1,000 ft southeast of the Anaheim Bay East Jetty. The breakwater had a 12-ft-wide crest width with a 0.0 ft el, a 1V:4H seaward slope, and a 1V:2H shoreward slope. Armor stone weights ranged from 7 to 15 tons.

Tracer tests

24. Tracer tests were conducted for all test plans to determine erosion and accretion patterns. The test plans were limited to test waves from the most critical incident wave direction of approach (i.e., west-southwest) with respect to erosion and/or accretion.

Test Results

25. In evaluating test results, the relative merits of various test plans were based on the movement of sediment tracer material in the model (erosion and accretion patterns). The changes in shoreline as a result of the movement of tracer material were documented in photographs, and these shoreline configurations also were plotted on plates.

Base tests

26. Preliminary tests were conducted for the initial sand fill to determine sediment erosion and accretion patterns for wave conditions from various directions. The originally constructed sandfill was initially subjected to test waves from south. It was first exposed to 5-sec, 7-ft waves and then 9-sec, 8-ft waves. Tracer material moved in a northwesterly direction toward the Anaheim Bay East Jetty. Accretion occurred adjacent to the jetty and some material moved seaward and deposited in deeper water south of the jetty. Material also moved through the voids of the jetty and deposited on the bayside of the structure. Erosion occurred along most of the length of the sandfill. Shoreline changes as a result of preliminary tests for waves from the south are shown in Plate 1. The resulting shoreline configuration for test waves from south was subjected to test waves from south-southwest (7-sec, 8-ft and 13-sec, 8-ft test waves). Additional accretion occurred adjacent to the jetty with erosion occurring at the southeasternmost end of the sandfill. Shoreline changes resulting from waves from south-southwest for preliminary tests are shown in Plate 2. The

resulting shoreline then was subjected to 5-sec, 7-ft and 11-sec, 10-ft test waves from southwest. The smaller 7-ft waves caused very little change in the shoreline configuration; however, the larger 10-ft waves resulted in erosion of the shoreline adjacent to the east jetty and slight accretion at the southeasternmost portion of the sandfill. These shoreline configurations are shown in Plate 3 for preliminary tests with waves from southwest. The resulting shoreline configuration for test waves from southwest was subjected to test waves from west-southwest (11-sec, 7-ft and 15-sec, 7-ft test waves). Both test wave conditions from west-southwest resulted in erosion of the shoreline adjacent to the Anaheim Bay East Jetty and southeasterly movement of sediment with accretion at the southeasternmost limits of the sandfill. The shoreline configurations for test waves from west-southwest are shown in Plate 4. These preliminary tests were conducted for representative test waves from the four test directions (for the same length of time, 2 hrs. in the model) to determine the movement of sediment (erosion and accretion) for waves from various directions. In general, wave conditions from south and south-southwest tended to move sediment northwesterly toward the east jetty, and wave conditions from west-southwest and southwest resulted in sediment movement away from the jetty toward the southeast.

27. Based on the hindcast wave data used for the Surfside-Sunset Beach model study, waves from west-southwest occur about 98.5 percent of the time; waves from southwest about 0.9 percent of the time; waves from south-southwest about 0.5 percent of the time; and waves from south occur about 0.1 percent of the time. To verify the movement of sediment and erosion adjacent to the East Jetty, the original (as constructed) sandfill was remolded in the model and subjected to wave action for a 10-hr cycle. Representative test waves from west-southwest were generated 98.5 percent of the 10-hr cycle; waves from southwest 0.9 percent; waves from south-southwest 0.5 percent; and waves from south 0.1 percent of the 10-hr cycle. This scenario, based on the hindcast data, insured that wave energy was distributed correctly over the incident wave directions, as defined in the wave hindcast.

28. Verification tests were initiated for representative test waves from west-southwest. Each test wave resulted in erosion of the shoreline and movement of sediment in a southeasterly direction. The various shoreline changes are shown in Plate 5 for representative waves from west-southwest. The resulting shoreline configuration then was subjected to representative

test waves from southwest, south-southwest, and south. These conditions resulted in little change to the shoreline configuration, as shown in Plate 6. The initial and final shoreline configurations, with areas showing erosion and accretion for the verification tests, are shown in Plate 7. Comparisons of the initial and final shoreline configurations also are shown in Photos 1 and 2. The erosion of the shoreline adjacent to the Anaheim Bay East Jetty and the movement of sediment in a southeasterly direction observed in the model study, based on historical data, is similar to what occurs in the prototype.

29. Additional base tests were conducted for test waves from west-southwest to establish a base from which to evaluate various improvement plans that were tested with the +3.0 ft swl. Test waves resulted in erosion of the shoreline adjacent to the jetty with accretion toward the southeastern portion of the sandfill, similar to the trends established with the +7.0 ft swl. Erosion for base test conditions with the +3.0 ft swl, however, was not as severe as it was for the +7.0 ft swl since less wave energy reaches the sandfill for the lower water level. The various shoreline changes for representative waves are shown in Plate 8, and the final shoreline configuration with areas showing erosion and accretion for base tests with the +3.0 ft swl are presented in Plate 9. Comparisons of the original and final shoreline configurations are also shown in Photos 3 and 4.

Improvement plans

30. Test results with Plan 1 installed in the model (a 300-ft-long offshore breakwater with a +5 ft crest el) are shown in Plate 10 for waves from west-southwest with the +7.0 ft swl. Erosion occurred adjacent to the Anaheim Bay East Jetty and sediment moved downcoast in a southeasterly direction. The +5.0 ft el breakwater was originally ineffective since it was covered with the +12 ft el sandfill. Test waves eventually eroded the sediment over the breakwater, and wave energy overtopping the structure continued to erode the shoreline in the lee of the breakwater. After the test cycle was completed the position of the shoreline was similar to its position after verification tests (without the breakwater in place). The configuration was subjected to an additional test cycle since the shoreline in the vicinity of the structure had not significantly receded. The initial and final shoreline configurations (after each test cycle) with areas of erosion and accretion are shown in Plate 11. Comparisons of the initial and final shoreline configuration (after the second test cycle) are shown in Photos 5

and 6. The breakwater appeared to be ineffective in reducing shoreline erosion for the +7.0 ft swl. Wave energy overtopping the structure continued to erode the shoreline in the lee of the breakwater. The water level in the model was adjusted to 0.0 ft and the shoreline configuration (that resulting from the +7.0 ft swl) was subjected to a test cycle for waves from west-southwest. Comparisons of the shoreline before and after testing with the 0.0 ft swl are shown in Photos 7 and 8. Since less wave energy was reaching the shoreline, the breakwater was not being overtopped and sediment began building up behind it in a tombolo formation.

31. At this point in the investigation test results were evaluated, and a swl of +3.0 ft was determined by SPL as more representative of normal prototype conditions than the +7.0 ft swl. The higher value represents an annual occurrence and would result in the most severe erosion of the sandfill, but the +3.0 ft value would represent mid-tidal conditions more representative of day-to-day conditions. The +3.0 ft swl, therefore, was used during testing throughout the remainder of the model study.

32. Shoreline configurations as a result of test waves from west-southwest with Plan 2 (a 1200-ft-long breakwater constructed at a -6 ft el and connected to the east jetty) installed are presented in Plate 12 for the +3.0 ft swl. Erosion occurred adjacent to the jetty and moved toward the southeast as it did for base tests with the +3.0 ft swl. Comparisons of the initial and final shoreline configuration after the test cycle are shown in Photos 9 and 10, and areas of erosion and accretion for Plan 2 are shown in Plate 13. It was noted that the severity or magnitude of erosion was not as great for Plan 2 as for base tests for identical test conditions.

33. Shoreline changes resulting from test waves from west-southwest with Plan 3 (a 600 ft offshore breakwater with a 0.0 ft crest el) installed in the model are shown in Plate 14 for the +3.0 ft swl. Erosion occurred adjacent to the Anaheim Bay East Jetty and sediment moved downcoast in a southeasterly direction. The 0.0 ft el breakwater was ineffective since it was covered with the +12 ft el sandfill. After the first test cycle was completed, the low-crested structure was still completely covered by the sandfill. Since the wave energy reaching the shoreline for the +3.0 ft swl was not as great as it was for the +7.0 ft swl used during testing of the Plan 1 offshore structure, five additional test cycles were completed. Each additional test cycle resulted in less erosion, and the shoreline appeared to

be stabilizing for waves with the +3.0 ft swl. As the shoreline eroded to the structure, wave overtopping occurred, and the shoreline in the lee of the structure continued to erode. The breakwater (at the 0.0 ft el) appeared to be ineffective. The initial and final shoreline configurations (after each test cycle) with areas of erosion and accretion are shown in Plate 15. Comparisons of the initial and final shoreline configuration (after the sixth test cycle) are shown in Photos 11 and 12.

Discussion of test results

34. Results preliminary tests indicated that, in general, waves from south and south-southwest will result in sediment movement in a northwesterly direction, and waves from southwest and west-southwest will move sediment in a southeasterly direction. These tests were conducted for the same time durations to determine sediment movement patterns for each direction. Wave hindcast data, however, indicates that waves approach Surfside-Sunset Beach predominantly from west-southwest (98.5 percent of the time). Verification tests indicated that the predominance of wave action from west-southwest will erode sediment adjacent to the Anaheim Bay East Jetty and result in a net movement of material to the southeast. Waves from southwest, south-southwest, and south changed the shoreline very little due to the short durations that waves from these directions occur. Beach erosion and sediment movement for these tests were similar to that observed in the prototype (based on historical data). Based on these test results the model was considered verified. A comparison of base test results for the +3.0 and +7.0 ft swl's indicated that the +7.0 ft swl resulted in more severe erosion for similar test conditions and time periods. This was expected, however, since more wave energy reaches the sandfill at the higher water levels.

35. Test results for the 300-ft-long offshore breakwater (el +5.0 ft) of Plan 1 indicated that the structure was not effective in reducing shoreline erosion for the +7.0 ft swl. Wave energy overtopping the breakwater continued to erode the shoreline behind the structure. By decreasing the water level to 0.0 ft, which in turn reduced the amount of wave energy reaching the shoreline, the breakwater appeared to be more effective. The shoreline rearranged and extended almost to the shoreside of the breakwater for the limited test series. These results indicate that erosion behind the structure is likely to occur during the higher stages of the tidal cycle where larger waves overtop the structure. For lower water conditions, when the breakwater

is not overtopped, the shoreline in the vicinity of the structure should be more stable.

36. Test results for the 1,200-ft-long jetty connected breakwater (el - 6 ft) of Plan 2 indicated that the structure was effective in reducing the rate of shoreline erosion in the vicinity of the East Jetty for the +3.0 ft swl. Even though these tests are qualitative, direct comparisons between base tests and Plan 2 revealed that the structure reduced shoreline erosion by about 40 percent adjacent to the jetty. The Plan 2 breakwater will not alleviate or stabilize the shoreline adjacent to the jetty, but based on test results, should reduce the rate of erosion.

37. Model tests indicated that the Plan 2 structure was effective in decreasing erosion adjacent to the East Jetty for the +3.0 ft swl. Its effectiveness, however, may be reduced for the higher water levels which, based on test results, result in more rapid erosion at the site. Caution should be exercised prior to construction in the prototype and consideration may be given to increasing the crest el of the breakwater.

38. Test results for the 600-ft-long offshore breakwater (el 0.0 ft) of Plan 3 indicated that the structure was not effective in reducing shoreline erosion for the +3.0 ft swl. Wave energy overtopping the structure continued to erode the shoreline in the lee of the breakwater. Results indicated that the shoreline erosion rate decreased in the latter portions of the test as the shoreline approached an equilibrium profile for the incident waves and wave direction at the +3.0 ft swl. However, the low-crested breakwater appeared to have little effect on erosion in its vicinity.

39. Observations during the study indicated very rapid initial erosion of the sandfill in the vicinity of the Anaheim Bay East Jetty. Erosion along the shoreline and jetty continued but its rate appeared to decrease as the shoreline became more stable for the test waves and swl's tested. The shoreline reoriented itself based on the angle of wave approach along the jetty. Test results also indicated, in general, that the shoreline will erode more rapidly for the higher water levels since more wave energy reaches the sandfill.

40. A comparison of initial and final shoreline configurations between existing conditions and Plan 1 is shown in Plate 16 with the +7.0 ft swl. For the +3.0 ft swl, a comparison of initial and final shoreline configurations between existing conditions and Plans 2 and 3 is shown in Plate 17.

PART V: CONCLUSIONS

41. Based on the results of the hydraulic model investigation reported herein, it is concluded that:

- a. Preliminary tests indicated sediment movement at Surfside-Sunset Beach to the northwest for test waves from south and south-southwest, and movement to the southeast for test waves from southwest and west-southwest.

- b. Verification tests at Surfside-Sunset Beach, based on durations of waves from various directions for hindcast data, revealed erosion of the shoreline adjacent to the Anaheim Bay East Jetty and a net movement of sediment material to the southeast and offshore similar to that observed in the prototype.

- c. Test results for the 300-ft-long offshore breakwater (el +5 ft) of Plan 1 indicated the structure was ineffective in reducing erosion of the shoreline for the +7.0 ft swl. For the 0.0 ft swl, however, it appeared to be more effective for the limited tests conducted.

- d. Test results for the 1,200-ft-long jetty attached breakwater (el -6 ft) of Plan 2 indicated the structure was effective in reducing the rate of erosion of the shoreline adjacent to the Anaheim Bay East Jetty for the +3.0 ft swl.

- e. Test results for the 600-ft-long offshore breakwater (el 0.0 ft) of Plan 3 indicated the structure was ineffective in reducing erosion of the shoreline for the +3.0 ft swl.

- f. Observations during the conduct of the study indicated very rapid initial erosion of the sandfill in the vicinity of the Anaheim Bay East Jetty. Erosion continued, but at a decreased rate, as the shoreline approached an equilibrium profile for the conditions tested. Test results also revealed that erosion will occur more rapidly for the higher water levels.

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Table 1

Estimated Magnitude of Wave Conditions Approaching Bolsa Chica from the Directions Indicated

Wave Height (ft)	Occurrences* per Wave Period (sec) 1.5-6.0	6.1-8.0	8.1-10.5	10.6-11.7	11.8-13.3	13.4-15.3	15.4-18.1	TOTAL
West								
0.0 - 3.3	1069	5240	9794	1182	140	2	---	17427
3.4 - 4.9	79	3718	5205	5404	611	10	---	15027
5.0 - 6.6	5	270	2037	1836	607	3	---	4758
6.7 - 8.2	----	1	372	254	102	2	---	731
8.3 - 9.8	----	----	9	2	1	----	---	12
TOTAL	1153	9229	17417	8678	1461	17	---	37955
West-Southwest								
0.0 - 3.3	48	120	349	174	99	36	---	826
3.4 - 4.9	12	93	386	1309	1783	209	12	3804
5.0 - 6.6	2	15	466	1057	3516	756	43	5855
6.7 - 8.2	----	3	511	885	2625	1373	92	5489
8.3 - 9.8	----	----	187	605	1063	875	65	2795
9.9 - 11.5	----	----	18	182	410	317	32	959
11.6 - 13.1	----	----	-----	26	169	136	15	346
13.2 - 14.7	----	----	-----	----	47	39	6	92
14.8 - 16.4	----	----	-----	----	----	5	---	5
TOTAL	62	231	1917	4238	9712	3746	265	20171

(Continued)

* Occurrences compiled for period 1956-1975. Each occurrence represents a 3-hr duration.

Table 1 (Concluded)

Wave Height (ft)	Occurrences* per Wave Period (sec) 1.5-6.0	6.1-8.0	8.1-10.5	10.6-11.7	11.8-13.3	13.4-15.3	15.4-18.1	TOTAL
Southwest								
0.0 - 3.3	8	10	39	6	----	2	---	65
3.4 - 4.9	----	----	7	11	2	8	1	29
5.0 - 6.6	1	2	25	8	11	----	---	47
6.7 - 8.2	----	3	11	3	11	----	---	28
8.3 - 9.8	----	----	4	3	7	2	---	16
TOTAL	9	15	86	31	31	12	1	185
South-Southwest								
0.0 - 3.3	----	11	40	----	----	----	---	51
3.4 - 4.9	5	1	2	----	----	----	---	8
5.0 - 6.6	----	7	14	1	----	----	---	22
6.7 - 8.2	----	8	10	2	1	----	---	21
TOTAL	5	27	66	3	1	----	---	102
South								
0.0 - 3.3	2	----	3	----	----	----	---	5
3.4 - 4.9	2	----	-----	----	----	----	---	2
5.0 - 6.6	2	----	2	----	----	----	---	4
6.7 - 8.2	----	2	7	----	----	----	---	9
TOTAL	6	2	12	----	----	----	---	20

* Occurrences compiled for period 1956-1975. Each occurrence represents a 3-hr duration.

Table 2

Estimated Magnitude of Wave Conditions Approaching Bolsa Chica from the Directions Indicated
(Approximate Location of Wave Generator in Model)

Wave Height (ft)	Occurrences* per Wave Period (sec) 1.5-6.0	6.1-8.0	8.1-10.5	10.6-11.7	11.8-13.3	13.4-15.3	15.4-18.1	TOTAL
				West				
1.5 - 4.0	1069	5240	9794	1182	140	2	---	17427
4.1 - 5.0	79	3718	5205	5404	611	10	---	15027
5.1 - 6.0	----	----	-----	----	----	----	---	-----
6.1 - 7.0	5	270	2037	1836	607	3	---	4758
7.1 - 8.0	----	1	372	254	102	2	---	731
8.1 - 9.0	----	----	9	2	1	----	---	12
TOTAL	1153	9229	17417	8678	1461	17	---	37955
				West-Southwest				
1.5 - 4.0	48	120	349	174	99	36	---	826
4.1 - 5.0	12	93	386	1309	1783	209	12	3804
5.1 - 6.0	----	----	-----	----	----	----	---	----
6.1 - 7.0	2	15	466	1057	3516	756	43	5855
7.1 - 8.0	----	----	-----	----	----	----	---	-----
8.1 - 9.0	----	3	511	885	2625	1373	92	5489
9.1 - 10.0	----	----	187	605	1063	875	65	2795
10.1 - 11.0	----	----	-----	----	----	----	---	-----
11.1 - 12.0	----	----	18	182	410	317	32	959
12.1 - 13.0	----	----	-----	26	169	136	15	346
13.1 - 14.0	----	----	-----	----	----	----	---	-----
14.1 - 15.0	----	----	-----	----	47	44	6	97
TOTAL	62	231	1917	4238	9712	3746	265	20171

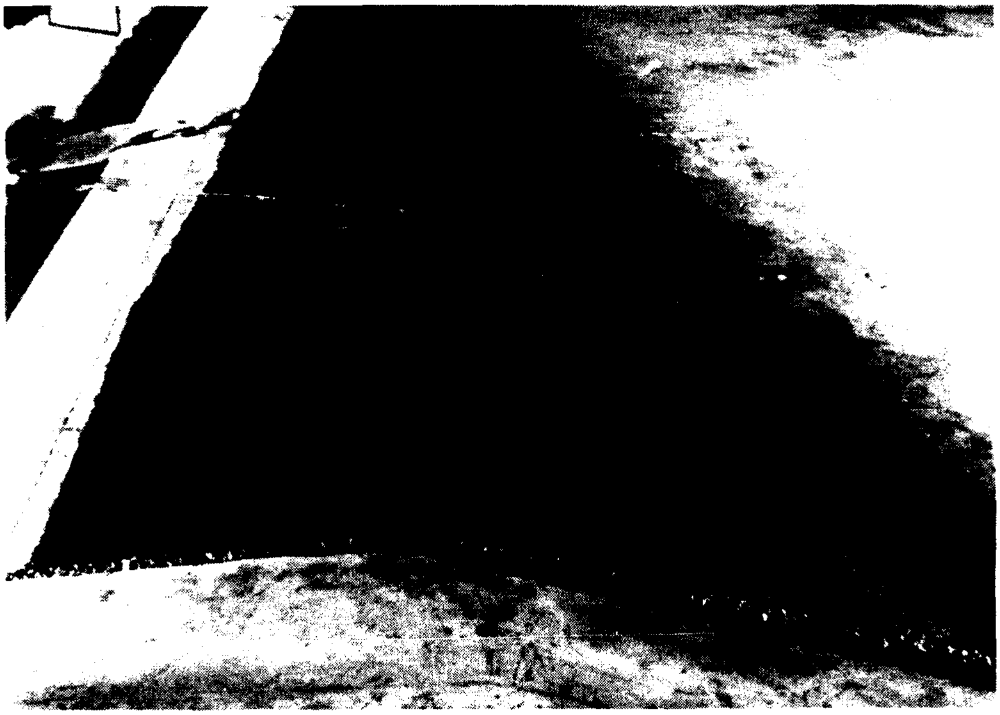
(Continued)

* Occurrences compiled for period 1956-1975. Each occurrence represents a 3-hr duration.

Table 2 (Concluded)

	Occurrences* per Wave Period (sec)							
Wave Height (ft)	1.5-6.0	6.1-8.0	8.1-10.5	10.6-11.7	11.8-13.3	13.4-15.3	15.4-18.1	TOTAL
				Southwest				
1.5 - 4.0	8	10	39	6	----	2	---	65
4.1 - 5.0	----	----	7	11	2	8	1	29
5.1 - 6.0	----	----	-----	----	----	----	---	-----
6.1 - 7.0	1	2	25	8	11	----	---	47
7.1 - 8.0	----	----	-----	----	----	----	---	-----
8.1 - 9.0	----	3	11	3	11	----	---	28
9.1 - 10.0	----	----	4	3	7	2	---	16
TOTAL	9	15	86	31	31	12	1	185
				South-Southwest				
1.5 - 4.0	----	11	40	----	----	----	---	51
4.1 - 5.0	5	1	2	----	----	----	---	8
5.1 - 6.0	----	----	-----	----	----	----	---	-----
6.1 - 7.0	----	7	14	1	----	----	---	22
7.1 - 8.0	----	8	10	2	1	----	---	21
TOTAL	5	27	66	3	1	----	---	102
				South				
1.5 - 4.0	2	----	3	----	----	----	---	5
4.1 - 5.0	2	----	-----	----	----	----	---	2
5.1 - 6.0	----	----	-----	----	----	----	---	-----
6.1 - 7.0	2	----	2	----	----	----	---	4
7.1 - 8.0	----	2	7	----	----	----	---	9
TOTAL	6	2	12	----	----	----	---	20

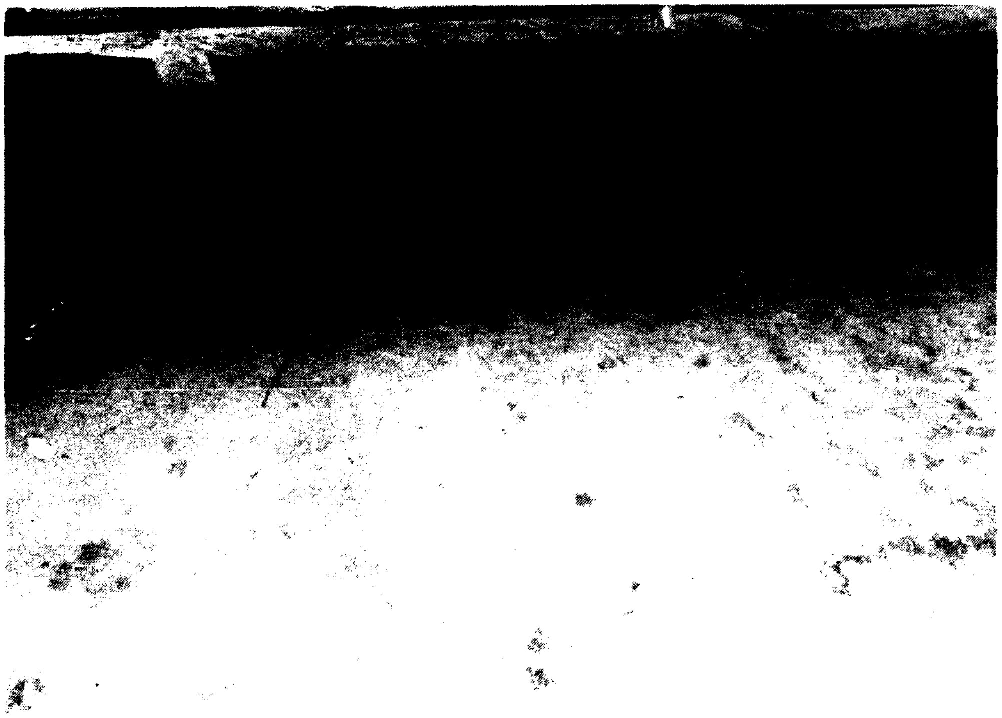
* Occurrences compiled for period 1956-1975. Each occurrence represents a 3-hr duration.



a. Initial shoreline configuration for verification tests

b. Final shoreline configuration for verification tests

Photo 1. Comparison of initial and final shoreline configuration for verification tests (looking southerly downcoast); swl = +7.0 ft



a. Initial shoreline configuration for verification tests

b. Final shoreline configuration for verification tests

Photo 2. Comparison of initial and final shoreline configuration for verification tests (looking shoreward); swl = +7.0 ft

a. Initial shoreline configuration for base tests

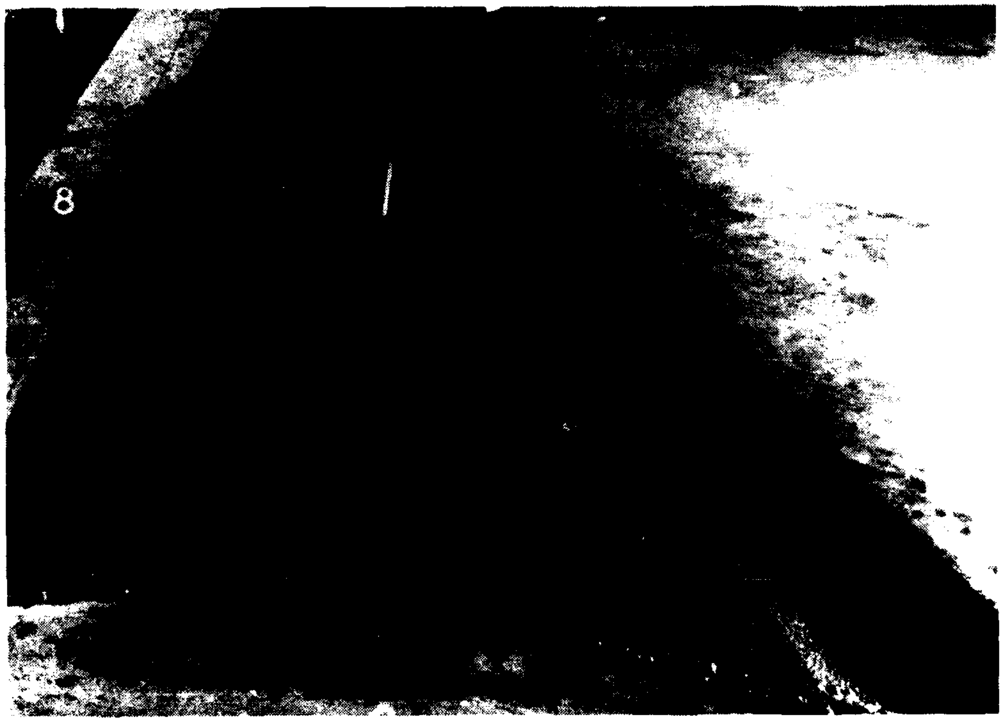
b. Final shoreline configuration for base tests

Photo 3. Comparison of initial and final shoreline configuration for base tests (looking southerly downcoast); swl = +3.0 ft

a. Initial shoreline configuration for base tests

b. Final shoreline configuration for base tests

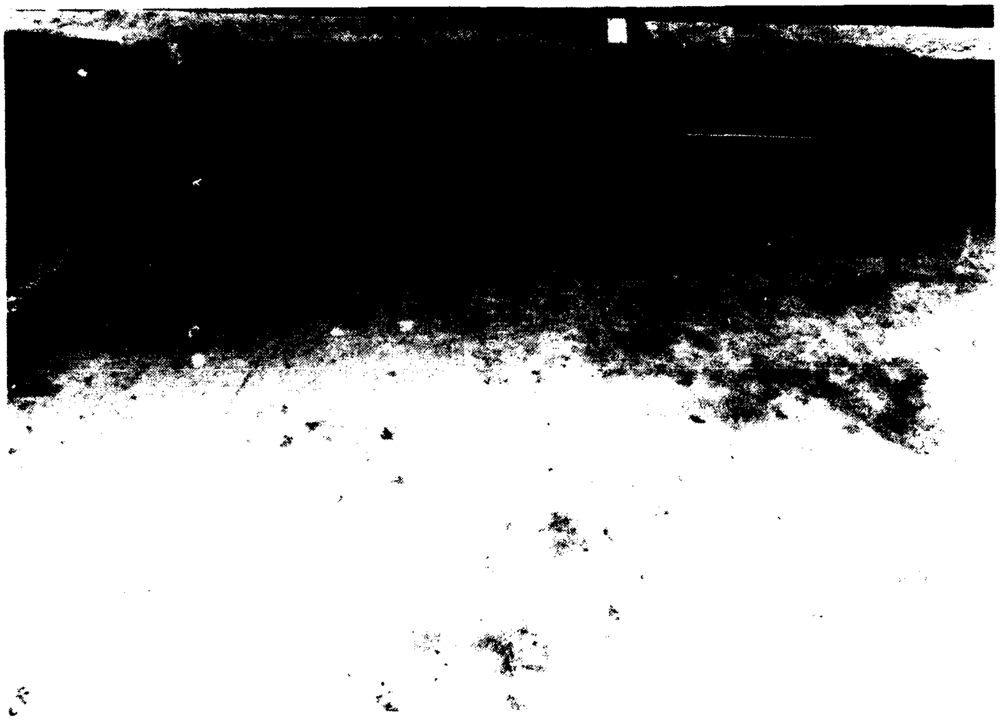
Photo 4. Comparison of initial and final shoreline configuration for base tests (looking shoreward); swl = +3.0 ft



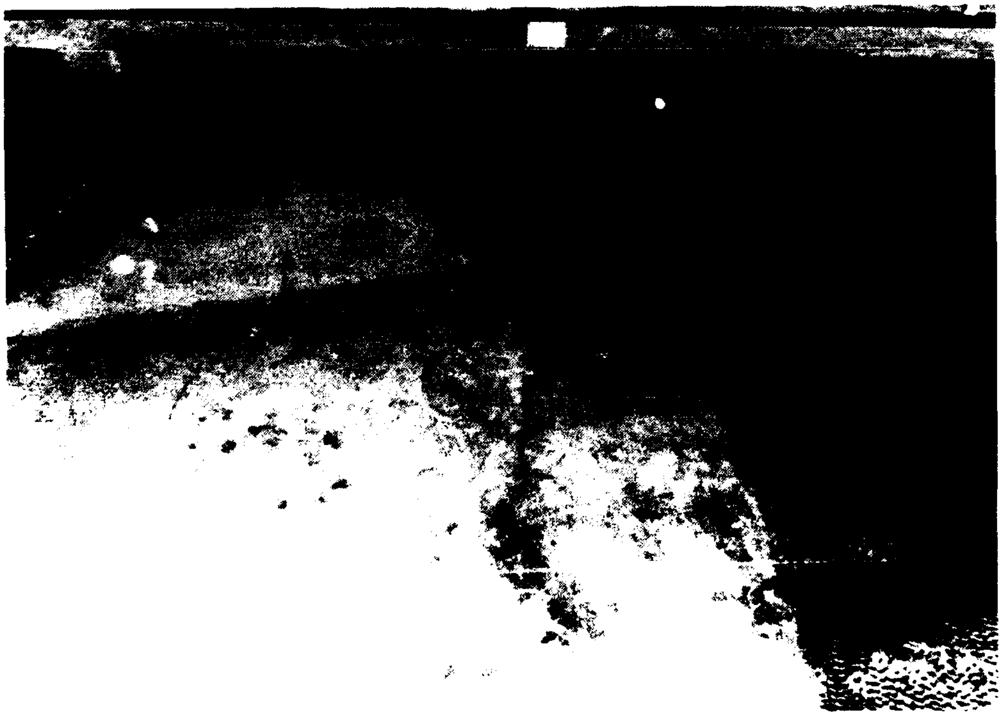
a. Initial shoreline configuration for Plan 1

b. Final shoreline configuration for Plan 1 (after second test cycle)

Photo 5. Comparison of initial and final shoreline configuration for Plan 1 (looking southerly downcoast); swl = +7.0 ft



a. Initial shoreline configuration for Plan 1



b. Final shoreline configuration for Plan 1 (after second test cycle)

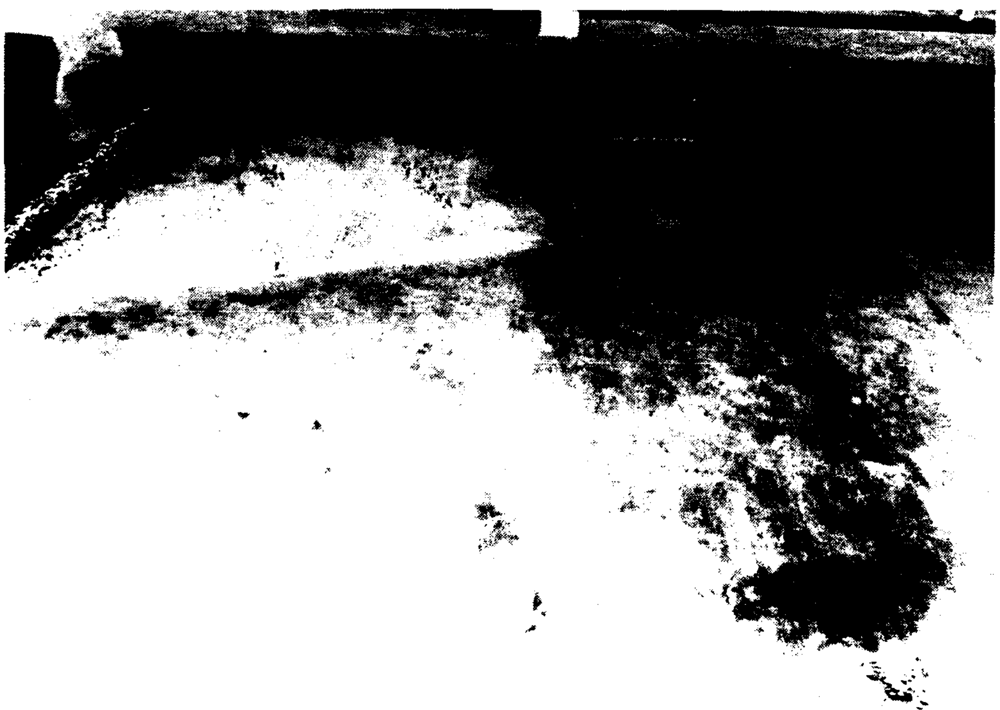
Photo 6. Comparison of initial and final shoreline configuration for Plan 1 (looking shoreward); swl = +7.0 ft

a. Initial shoreline configuration for Plan 1 (resulting from tests at +7.0 ft swl)

b. Final shoreline configuration for Plan 1

Photo 7. Comparison of initial and final shoreline configuration Plan 1 (looking southerly downcoast); swl = +0.0 ft

a. Initial shoreline configuration for Plan 1 (resulting from tests at +7.0 ft swl



b. Final shoreline configuration for Plan 1

Photo 8. Comparison of initial and final shoreline configuration for Plan 1 (looking shoreward); swl = +0.0 ft

a. Initial shoreline configuration for Plan 2

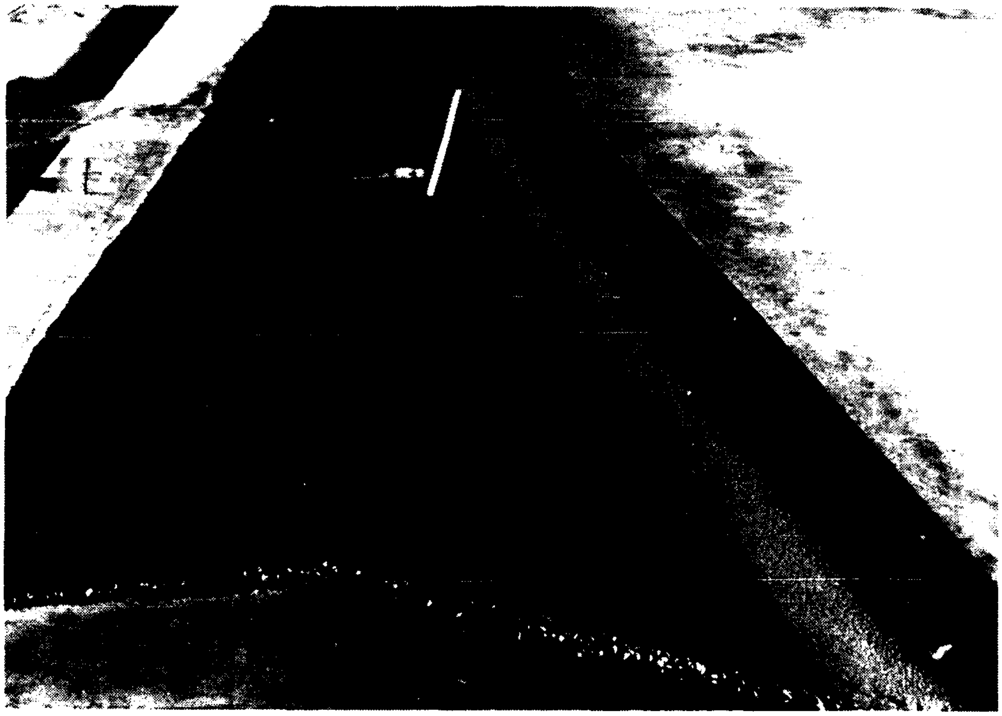
b. Final shoreline configuration for Plan 2

Photo 9. Comparison of initial and final shoreline configuration for Plan 2 (looking southerly downcoast); swl = +3.0 ft

a. Initial shoreline configuration for Plan 2

b. Final shoreline configuration for Plan 2

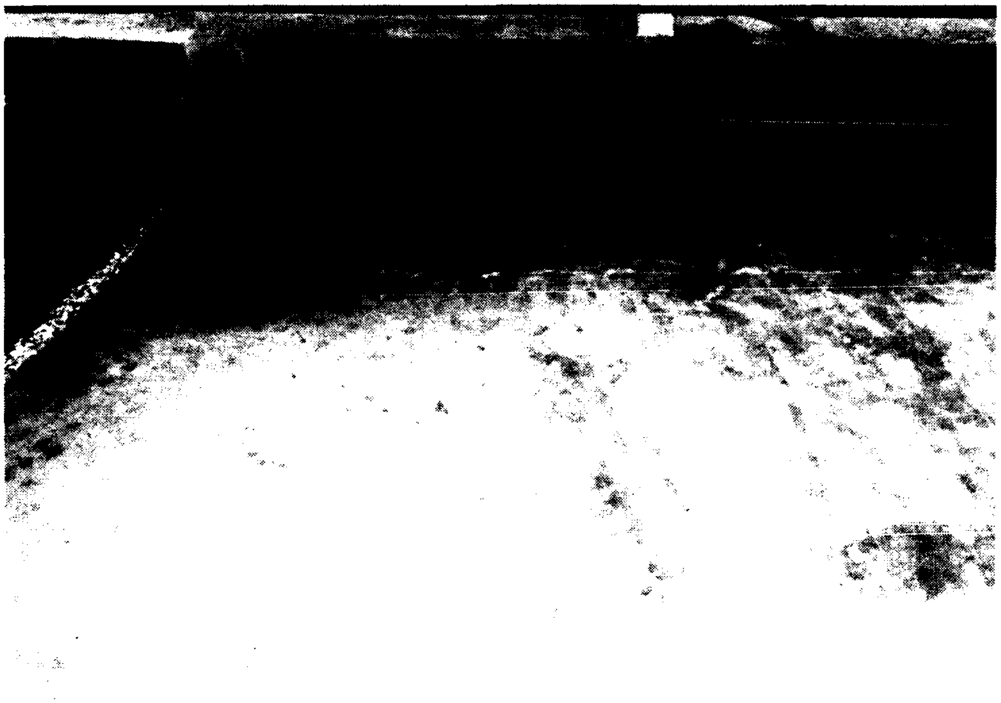
Photo 10. Comparison of initial and final shoreline configuration for Plan 2 (looking shoreward); swl = +3.0 ft



a. Initial shoreline configuration for Plan 3

b. Final shoreline configuration for Plan 3 (after sixth test cycle)

Photo 11. Comparison of initial and final shoreline configuration for Plan 3 (looking southerly downcoast); swl = +3.0 ft



a. Initial shoreline configuration for Plan 3

b. Final shoreline configuraion for Plan 3 (after sixth test cycle)

Photo 12. Comparison of initial and final shoreline configuration for Plan 3 (looking shoreward); swl = +3.0 ft

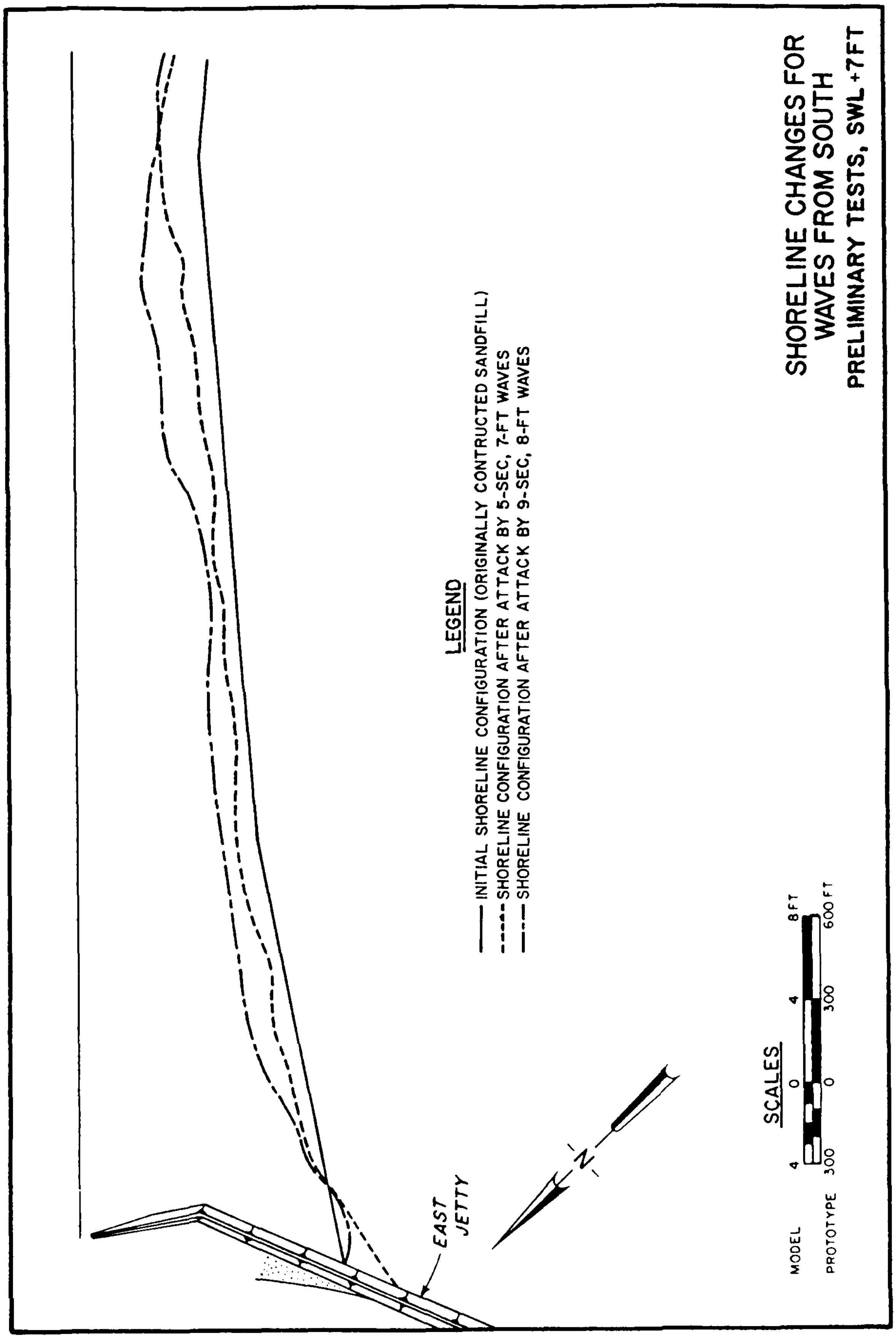
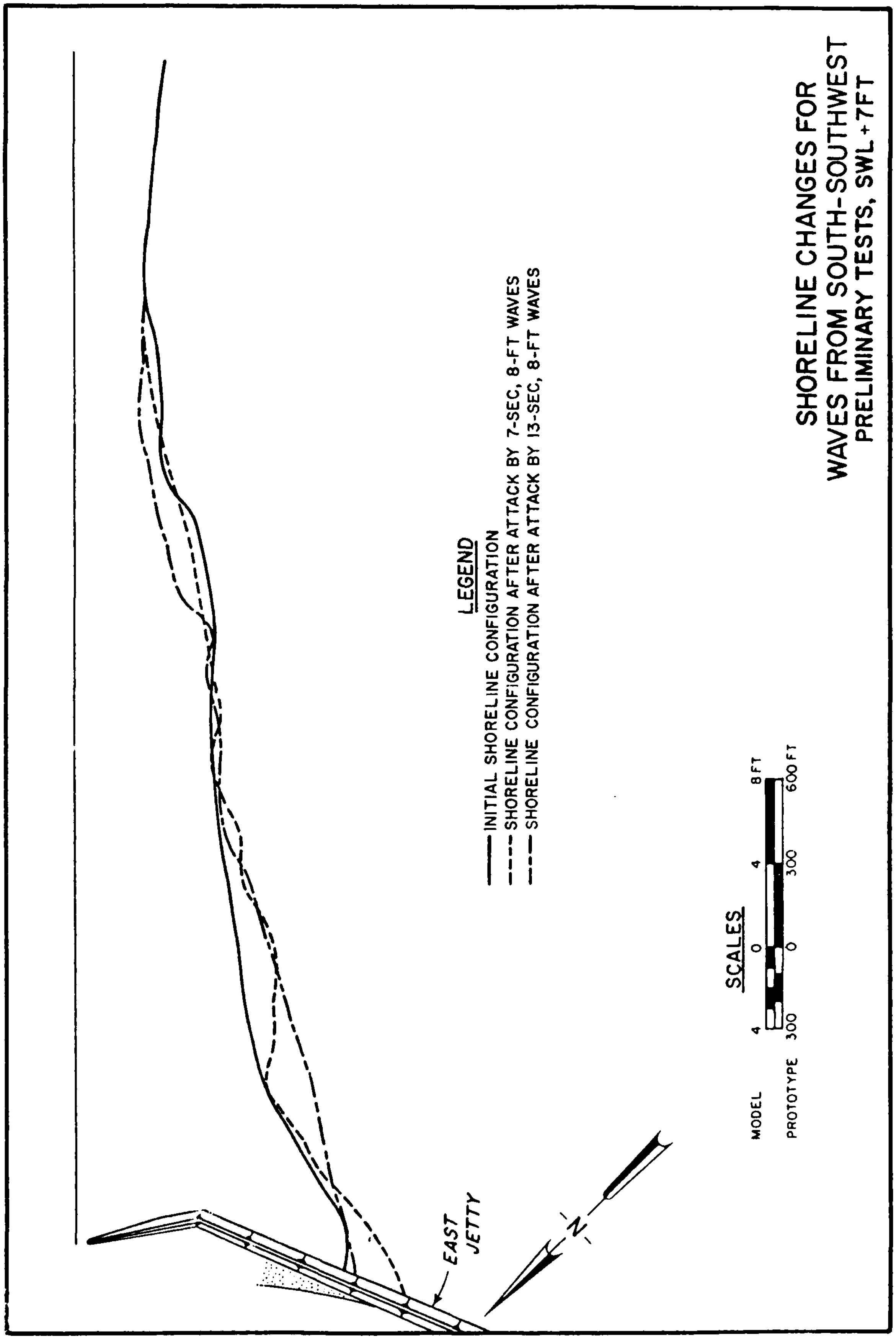
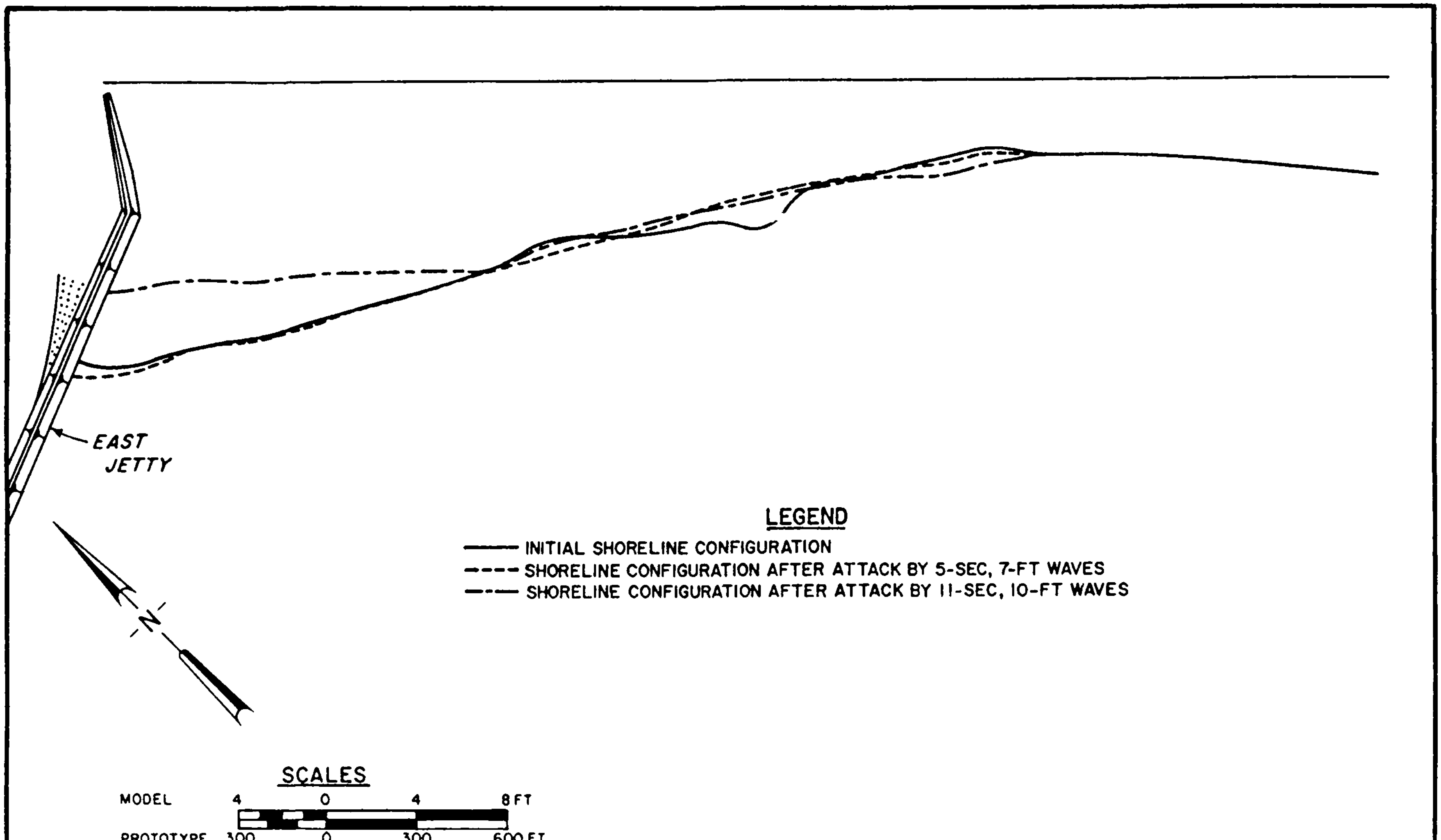

LEGEND
INITIAL SHORELINE CONFIGURATION (ORIGINALLY CONTRUCTED SANDFILL)
SHORELINE CONFIGURATION AFTER ATTACK BY 5-SEC, 7-FT WAVES
SHORELINE CONFIGURATION AFTER ATTACK BY 9-SEC, 8-FT WAVES
EAST JETTY
N
SCALES
MODEL 4 0 4 8 FT
PROTOTYPE 300 0 300 600 FT
SHORELINE CHANGES FOR WAVES FROM SOUTH
PRELIMINARY TESTS, SWL +7FT

PLATE 1

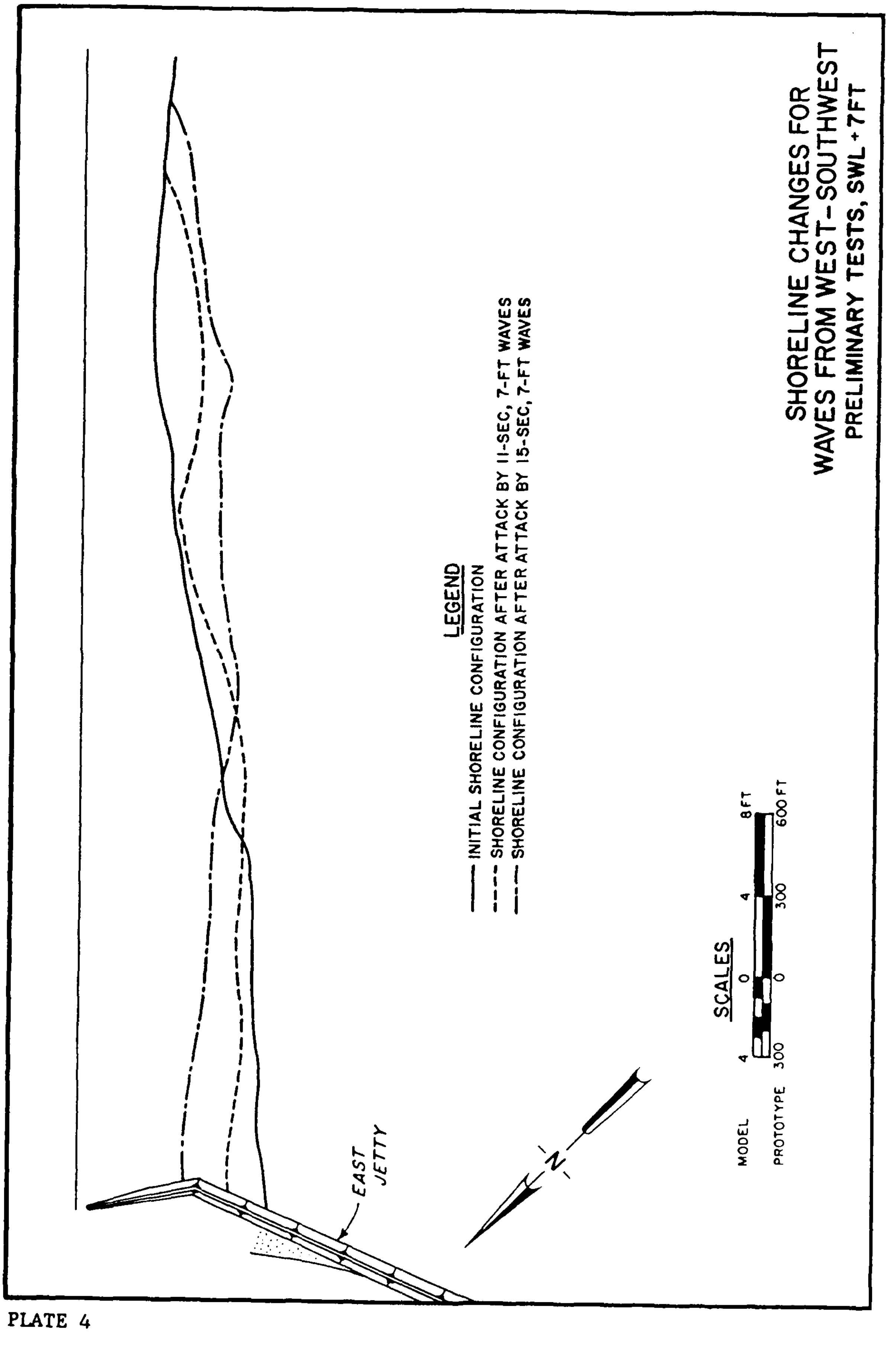


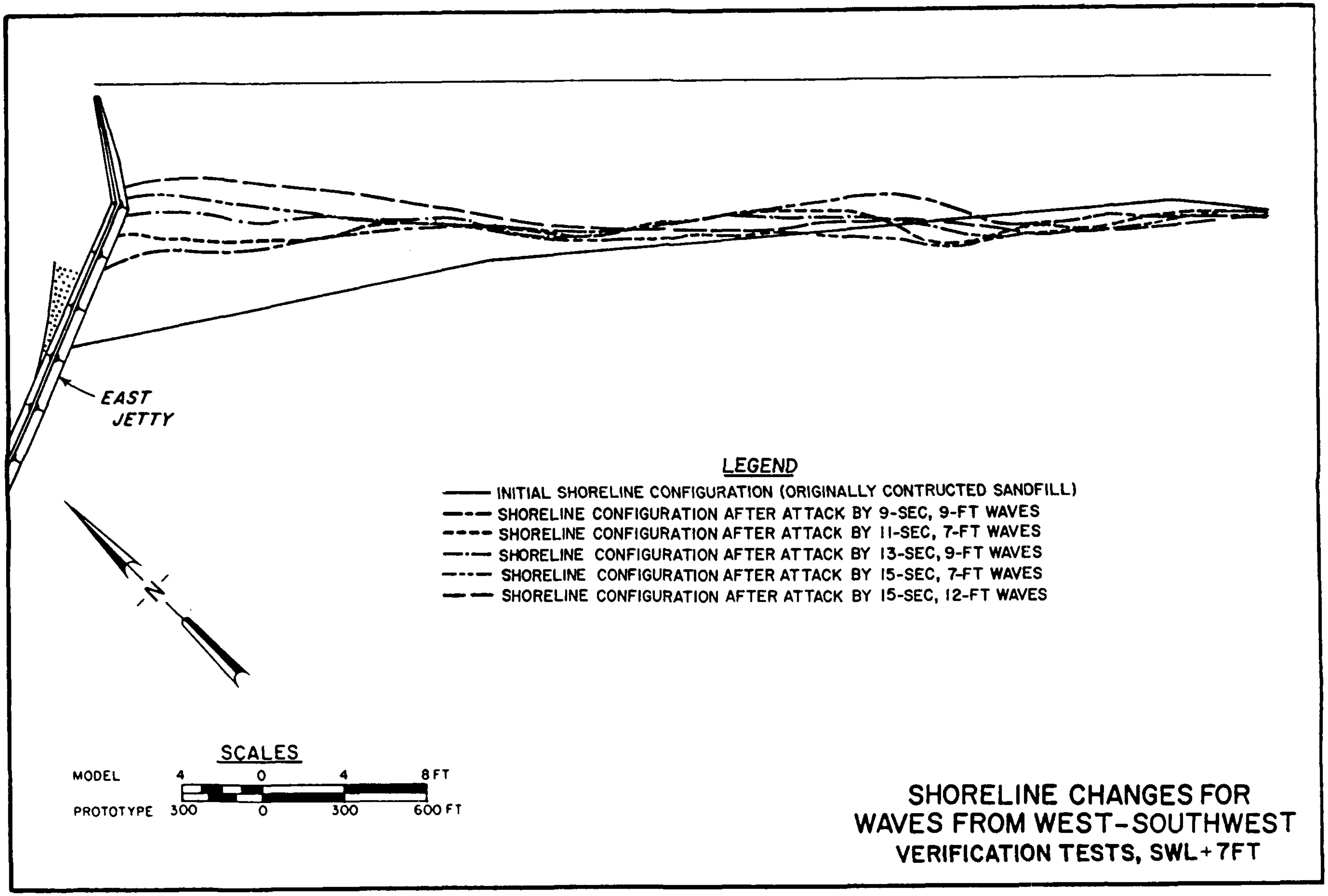
SHORELINE CHANGES FOR WAVES FROM SOUTH-SOUTHWEST PRELIMINARY TESTS, SWL +7FT

PLATE 2

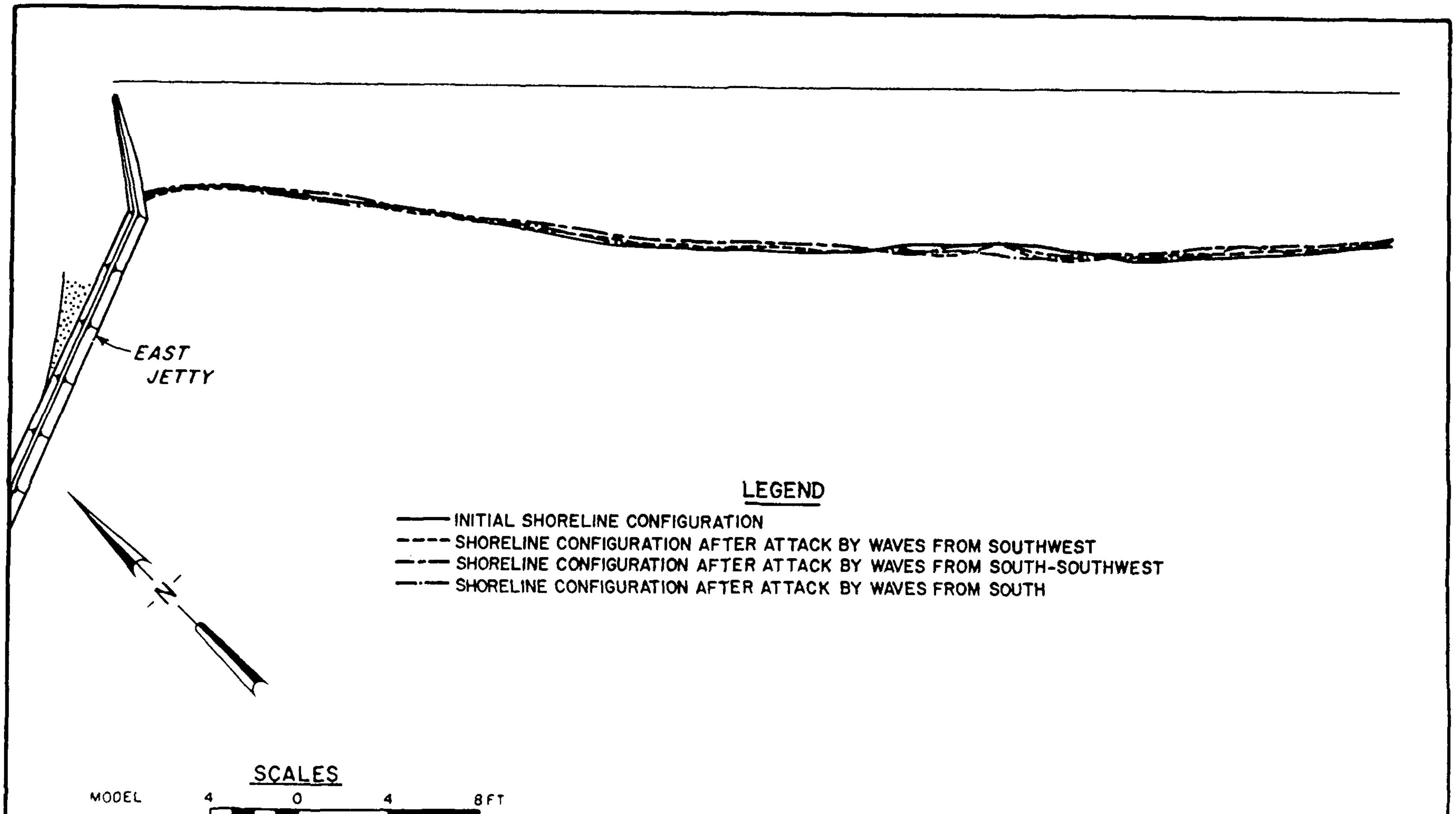


SHORELINE CHANGES FOR
WAVES FROM SOUTHWEST
PRELIMINARY TESTS, SWL +7FT

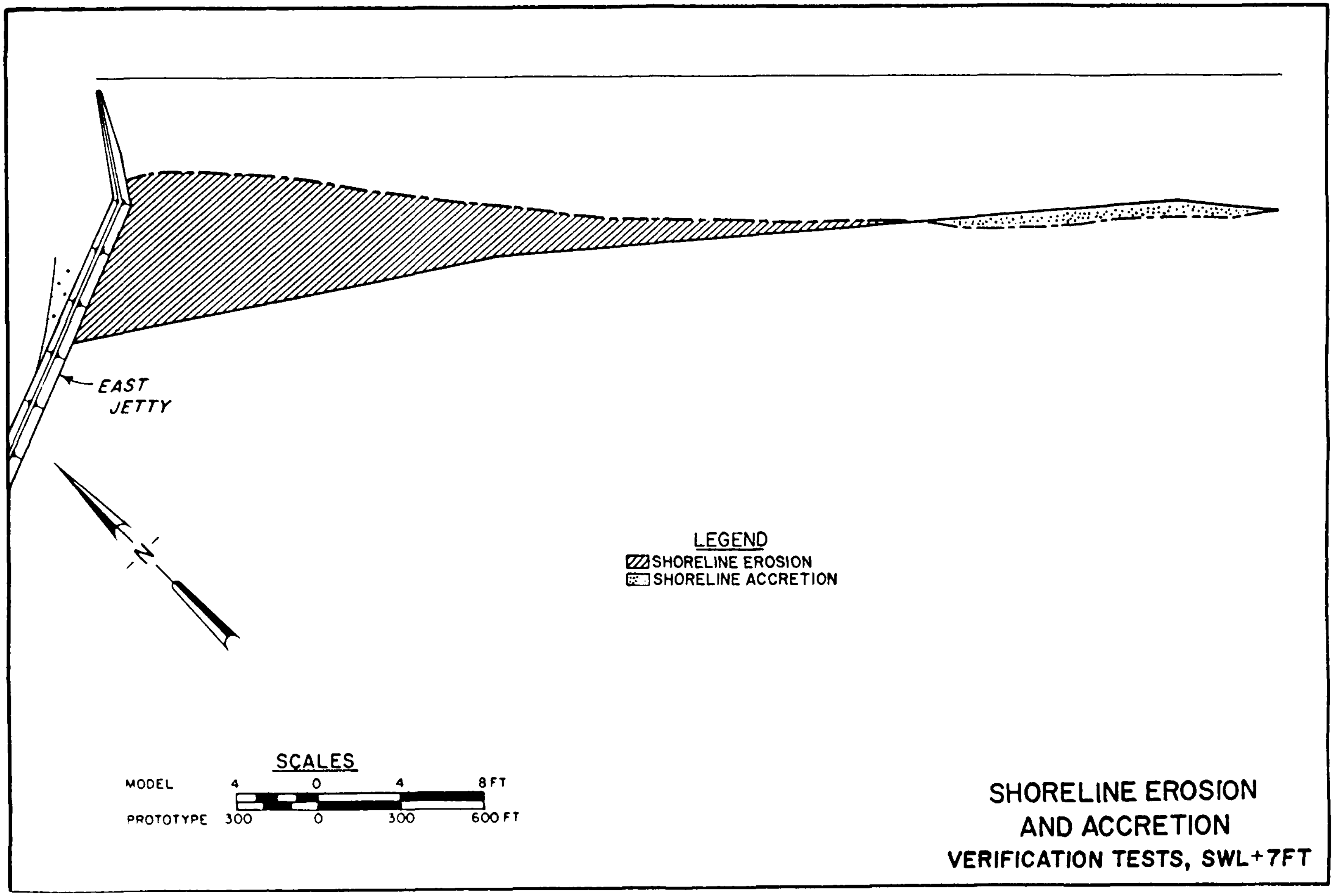

SHORELINE CHANGES FOR
WAVES FROM WEST-SOUTHWEST
PRELIMINARY TESTS, SWL +7FT
LEGEND
INITIAL SHORELINE CONFIGURATION
SHORELINE CONFIGURATION AFTER ATTACK BY 11-SEC, 7-FT WAVES
SHORELINE CONFIGURATION AFTER ATTACK BY 15-SEC, 7-FT WAVES
SCALES
MODEL
PROTOTYPE
4
0
4
8 FT
300
0
300
600 FT
EAST JETTY
N



SHORELINE CHANGES FOR
WAVES FROM WEST-SOUTHWEST
VERIFICATION TESTS, SWL + 7FT



SHORELINE CHANGES FOR
WAVES FROM SOUTHWEST, SOUTH-SOUTHWEST,
AND SOUTH
VERIFICATION TESTS, SWL+7FT



SHORELINE EROSION
AND ACCRETION
VERIFICATION TESTS, SWL+7FT

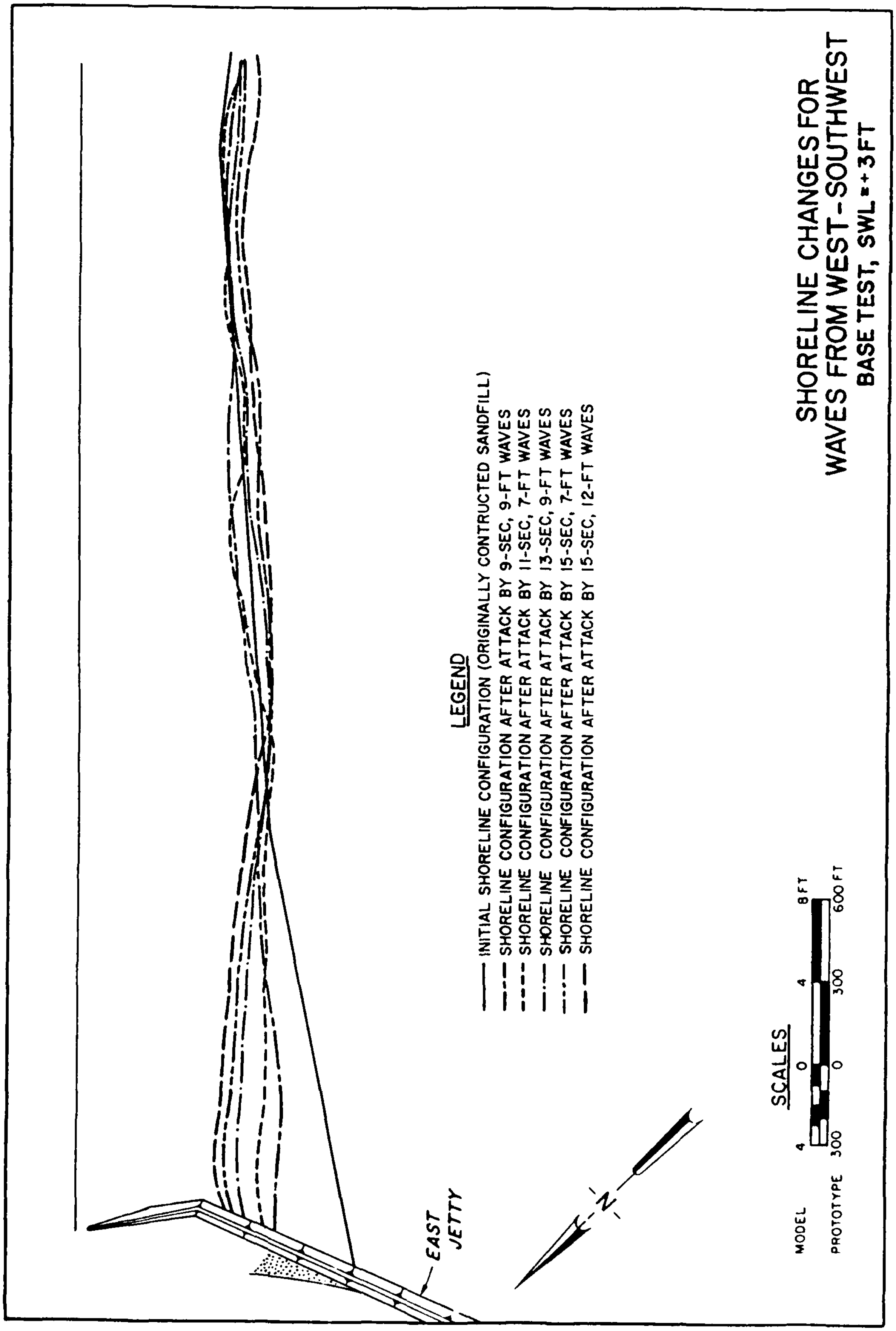
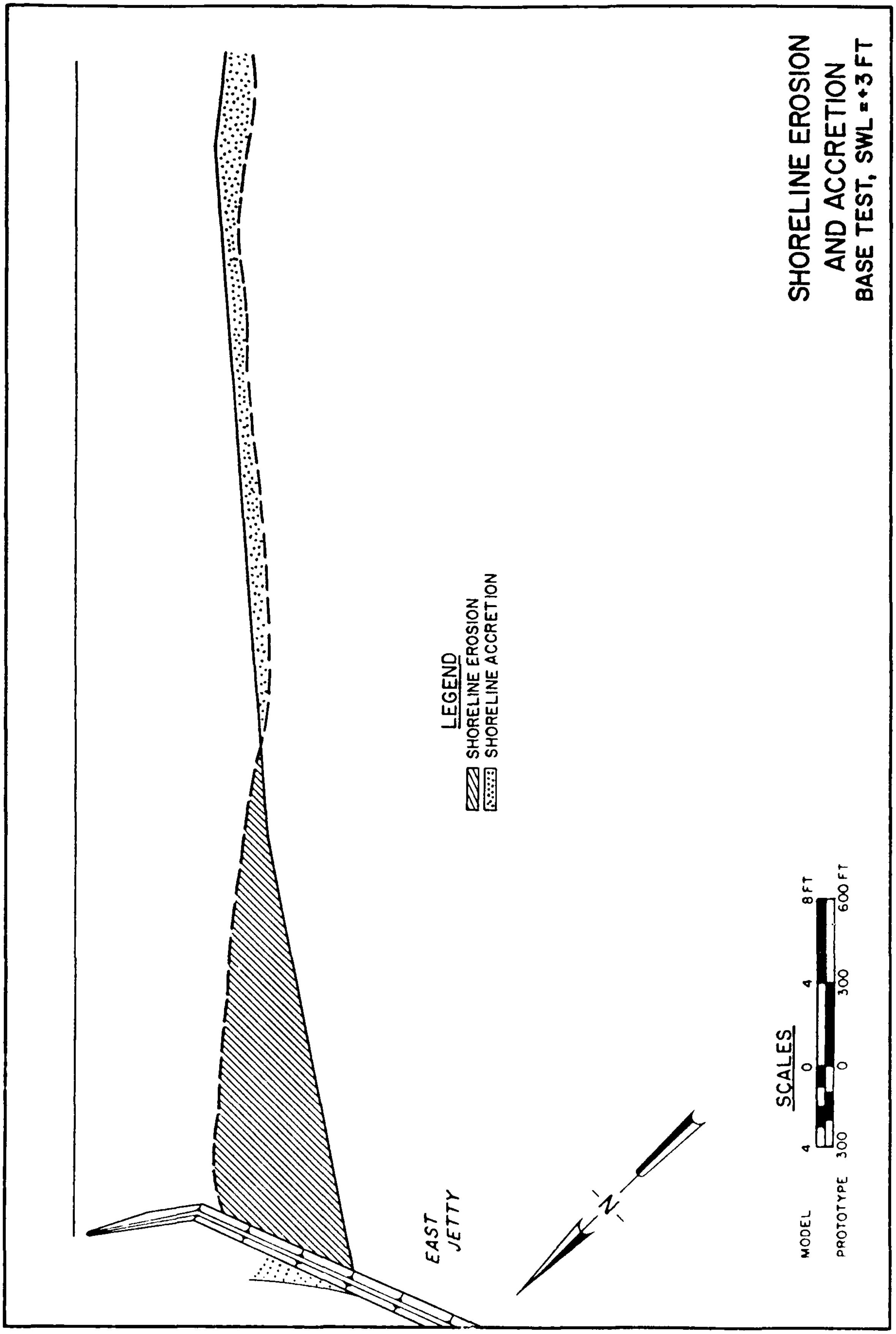
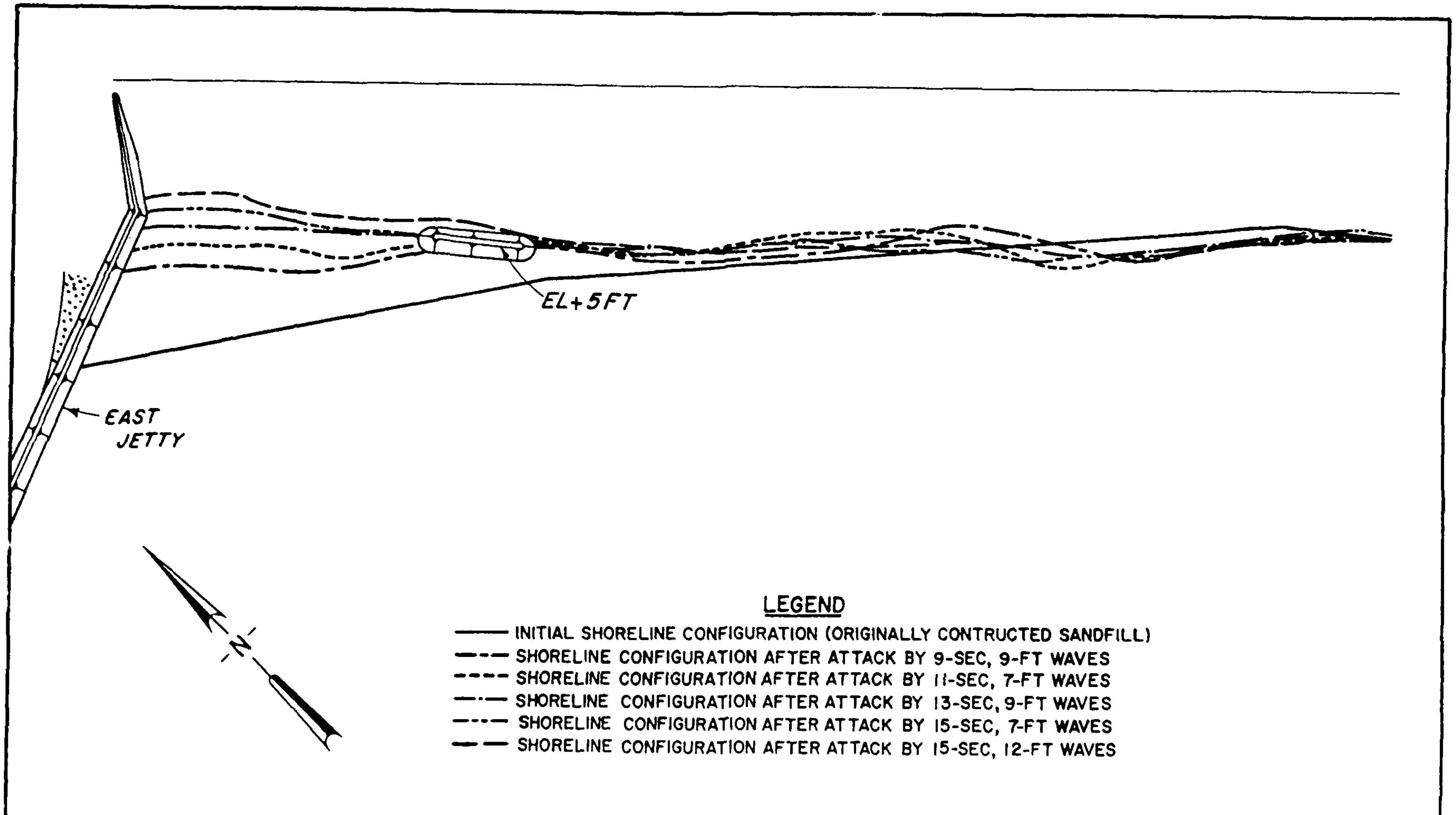

LEGEND
INITIAL SHORELINE CONFIGURATION (ORIGINALLY CONTRUCTED SANDFILL)
SHORELINE CONFIGURATION AFTER ATTACK BY 9-SEC, 9-FT WAVES
SHORELINE CONFIGURATION AFTER ATTACK BY 11-SEC, 7-FT WAVES
SHORELINE CONFIGURATION AFTER ATTACK BY 13-SEC, 9-FT WAVES
SHORELINE CONFIGURATION AFTER ATTACK BY 15-SEC, 7-FT WAVES
SHORELINE CONFIGURATION AFTER ATTACK BY 15-SEC, 12-FT WAVES
SCALES
MODEL 4 0 4 8 FT
PROTOTYPE 300 0 300 600 FT
EAST JETTY
N
SHORELINE CHANGES FOR
WAVES FROM WEST-SOUTHWEST
BASE TEST, SWL = +3 FT

PLATE 8

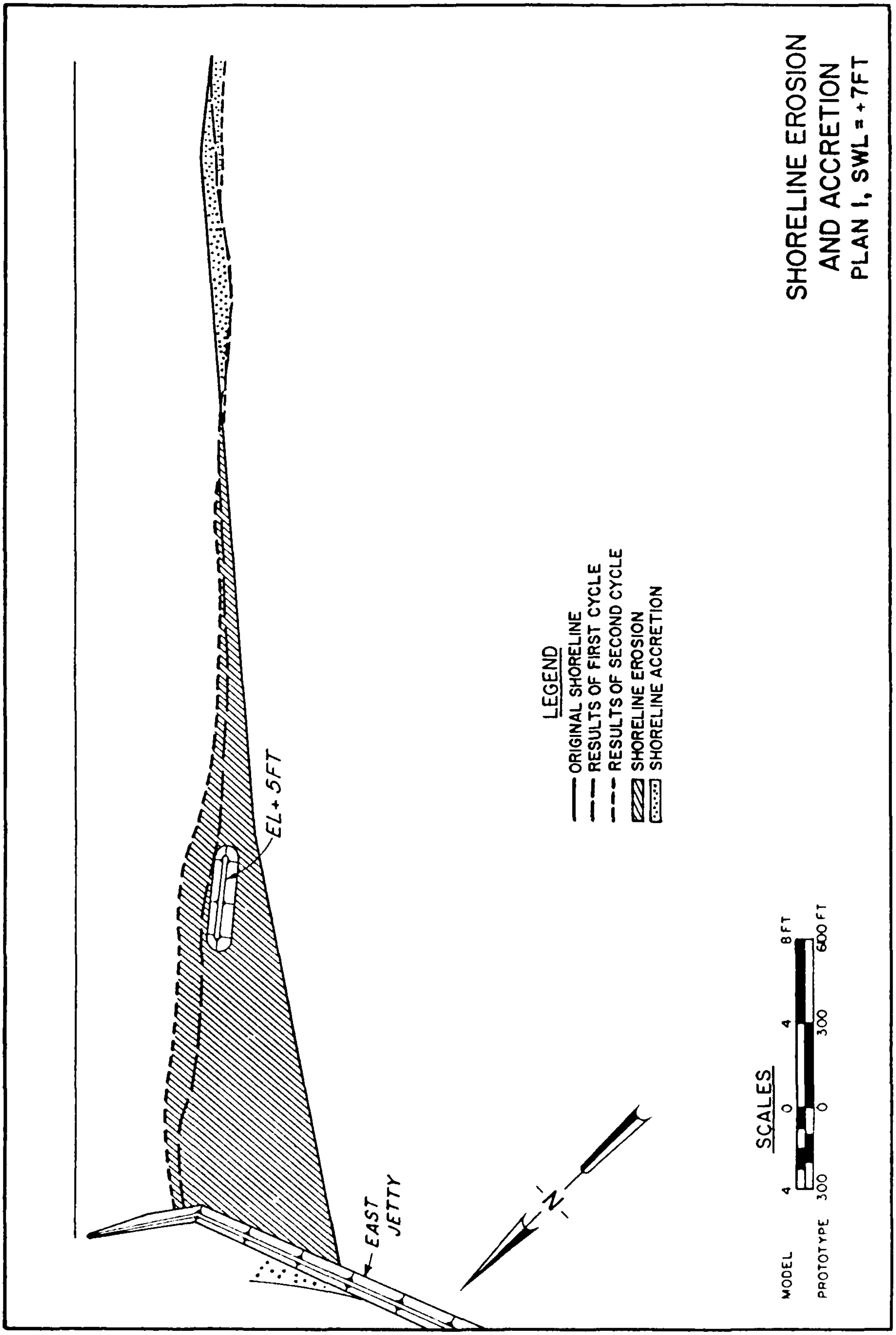


SHORELINE EROSION
AND ACCRETION
BASE TEST, SWL = +3 FT
LEGEND
SHORELINE EROSION
SHORELINE ACCRETION
SCALES
MODEL 4 0 4 8 FT
PROTOTYPE 300 0 300 600 FT
EAST JETTY
N

PLATE 9



SHORELINE CHANGES FOR
WAVES FROM WEST-SOUTHWEST
PLAN I, SWL = +7FT


SHORELINE EROSION
AND ACCRETION
PLAN I, SWL = +7FT
LEGEND
ORIGINAL SHORELINE
RESULTS OF FIRST CYCLE
RESULTS OF SECOND CYCLE
SHORELINE EROSION
SHORELINE ACCRETION
EL + 5FT
EAST
JETTY
N
SCALES
MODEL 4 0 4 8FT
PROTOTYPE 300 0 300 600FT

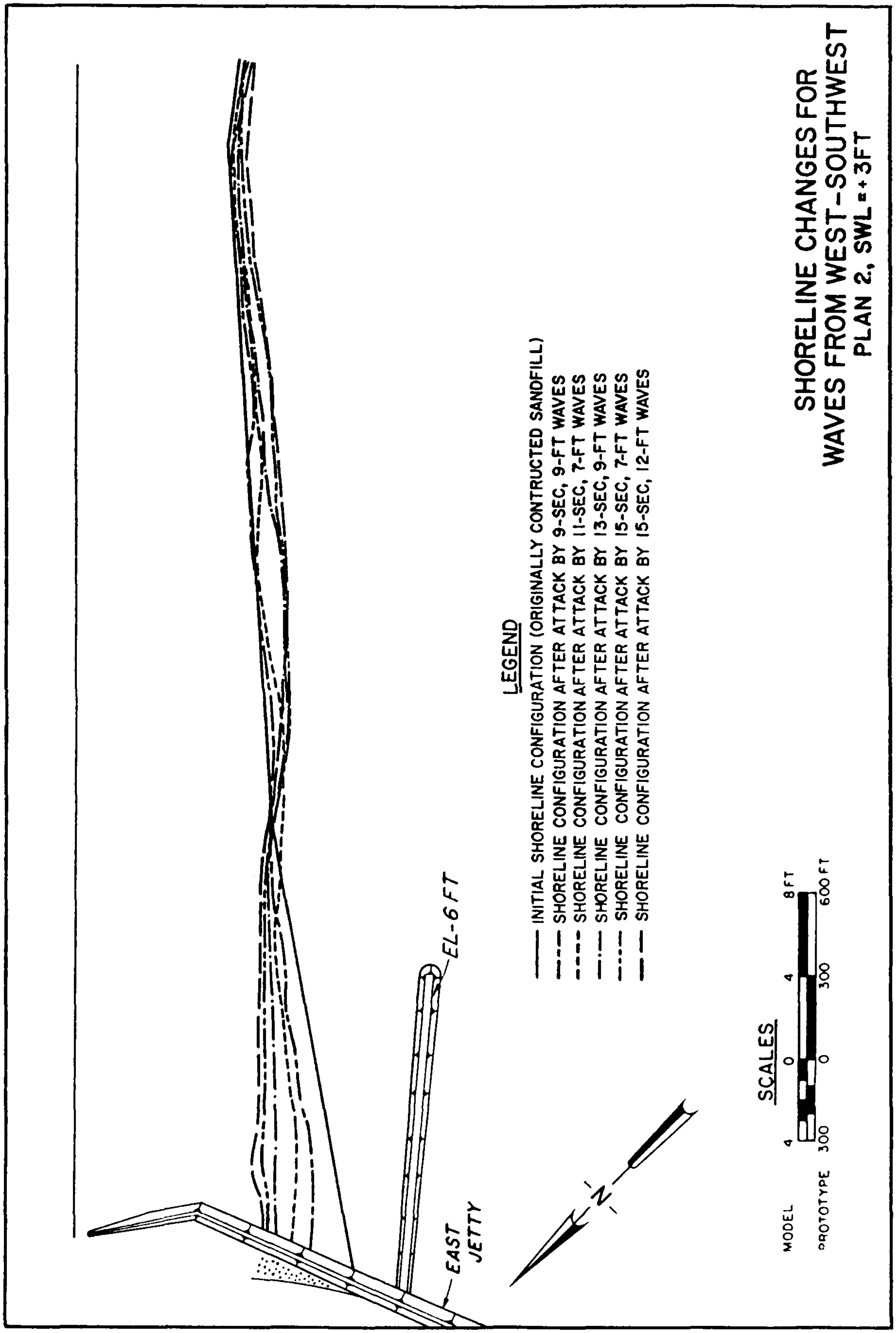
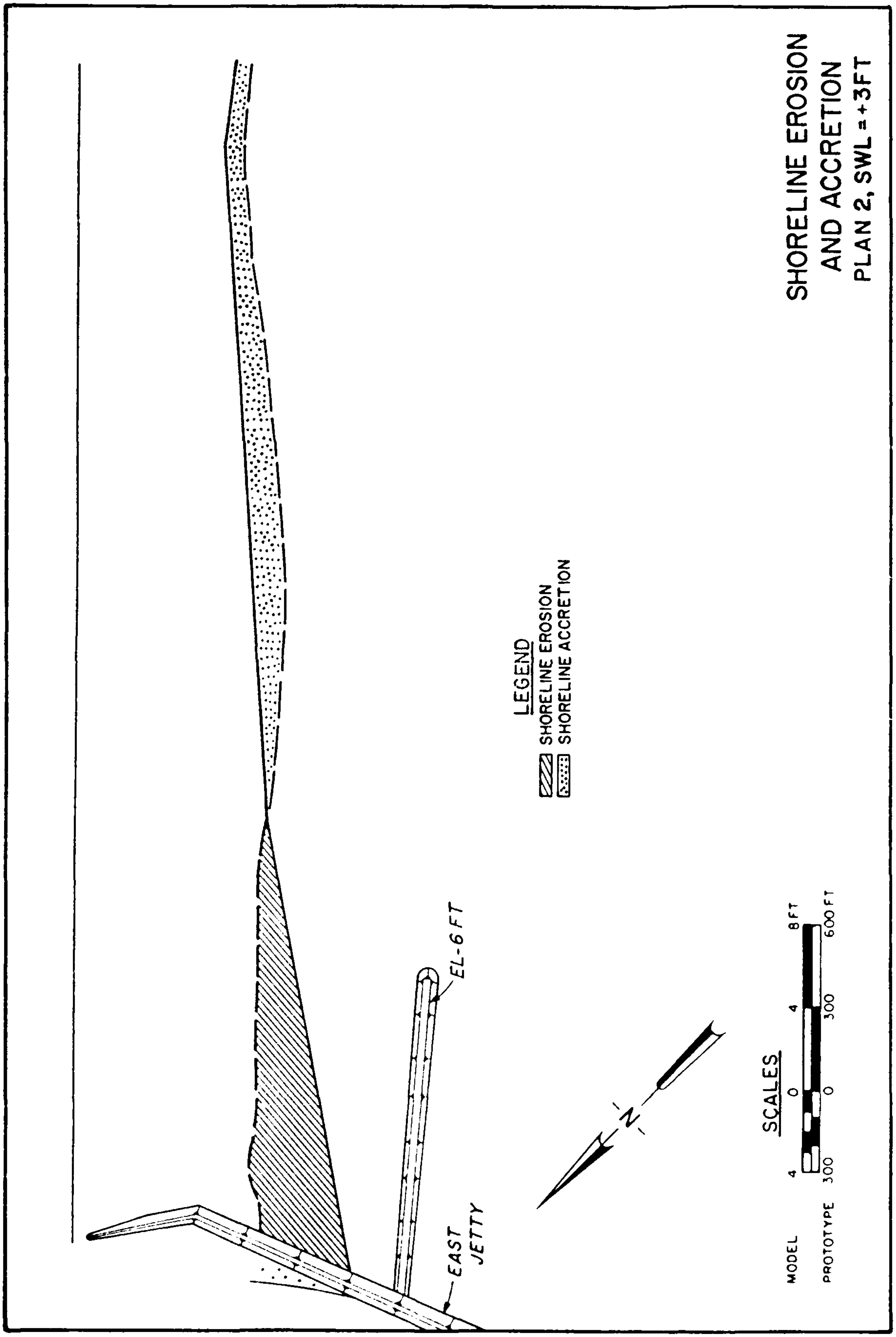
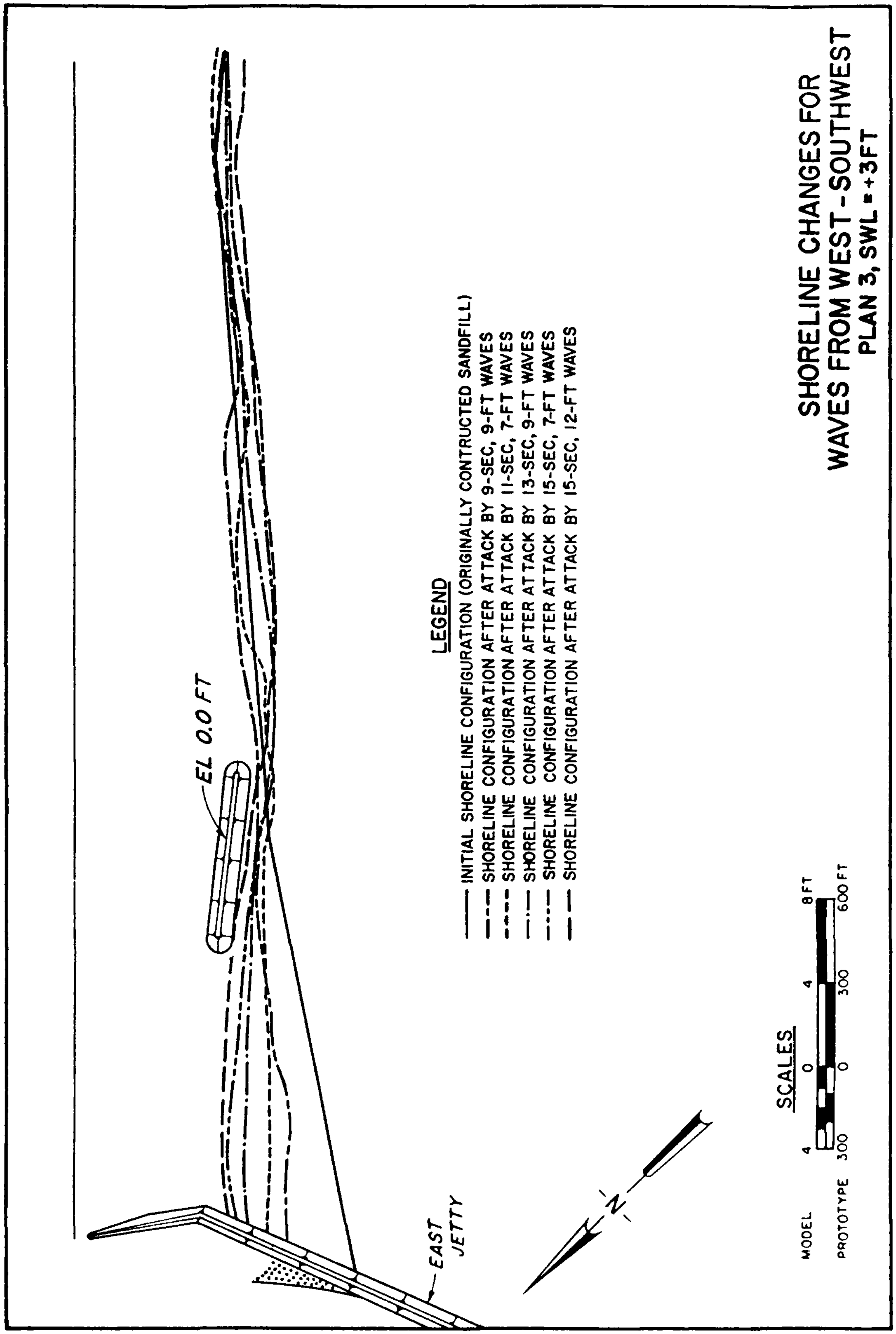
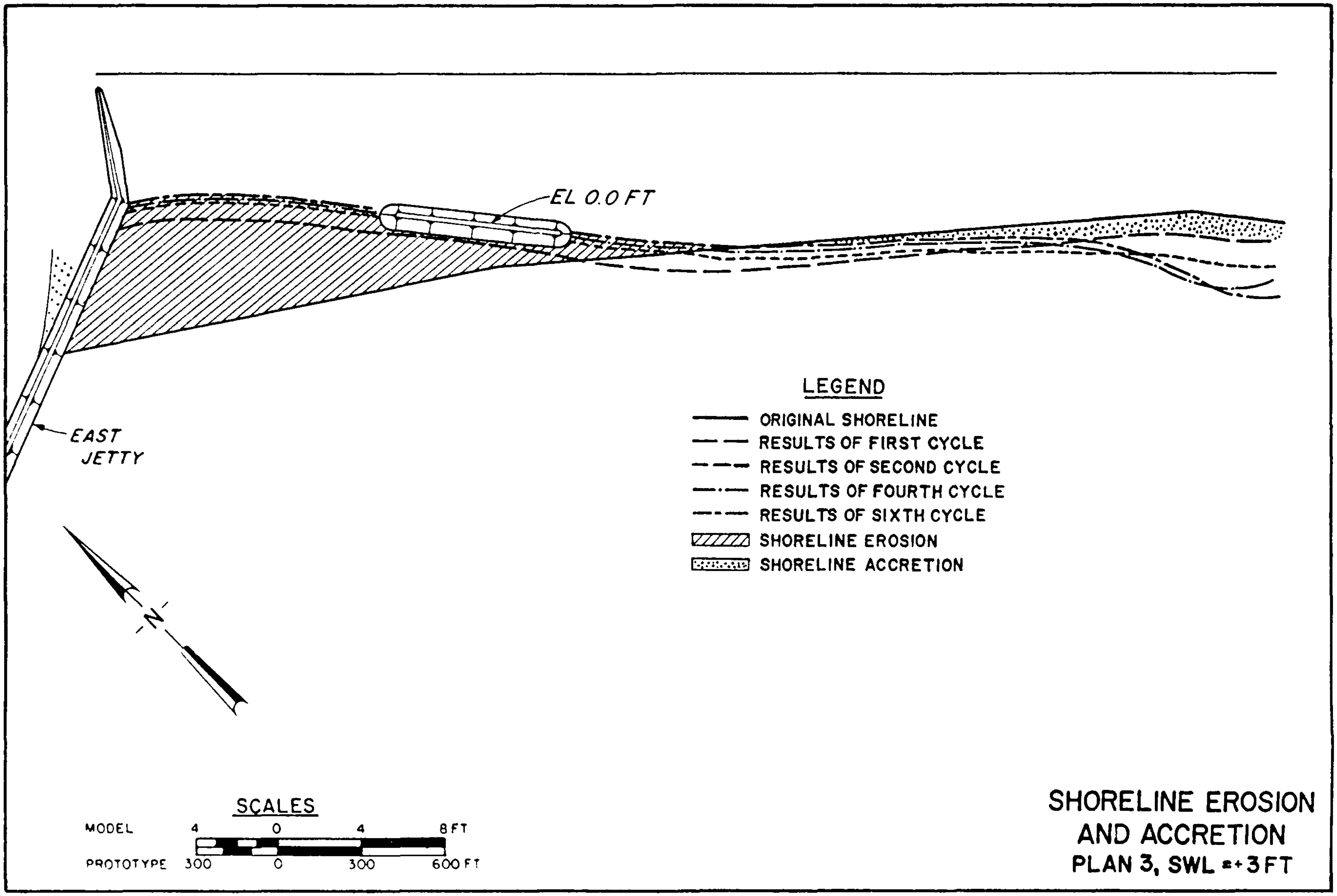

SHORELINE CHANGES FOR
WAVES FROM WEST-SOUTHWEST
PLAN 2, SWL = +3FT
LEGEND
INITIAL SHORELINE CONFIGURATION (ORIGINALLY CONTRUCTED SANDFILL)
SHORELINE CONFIGURATION AFTER ATTACK BY 9-SEC, 9-FT WAVES
SHORELINE CONFIGURATION AFTER ATTACK BY 11-SEC, 7-FT WAVES
SHORELINE CONFIGURATION AFTER ATTACK BY 13-SEC, 9-FT WAVES
SHORELINE CONFIGURATION AFTER ATTACK BY 15-SEC, 7-FT WAVES
SHORELINE CONFIGURATION AFTER ATTACK BY 15-SEC, 12-FT WAVES
EL-6 FT
EAST JETTY
N
SCALES
MODEL 4 0 4 8 FT
PROTOTYPE 300 0 300 600 FT

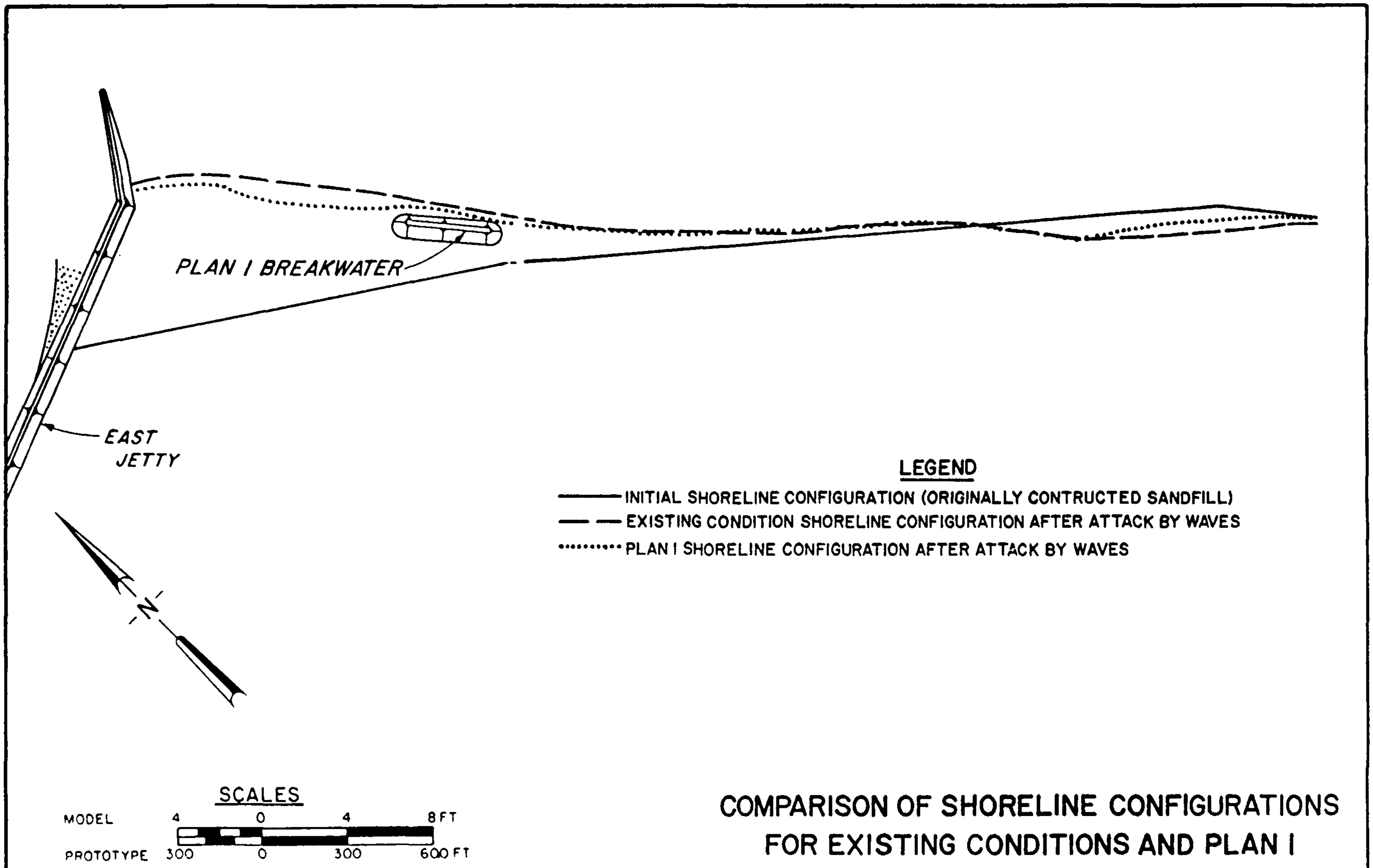
PLATE 12


SHORELINE EROSION
AND ACCRETION
PLAN 2, SWL = +3FT
LEGEND
SHORELINE EROSION
SHORELINE ACCRETION
EL-6 FT
EAST
JETTY
SCALES
MODEL 4 0 4 8 FT
PROTOTYPE 300 0 300 600 FT
N


SHORELINE CHANGES FOR
WAVES FROM WEST-SOUTHWEST
PLAN 3, SWL = +3FT
LEGEND
INITIAL SHORELINE CONFIGURATION (ORIGINALLY CONTRUCTED SANDFILL)
SHORELINE CONFIGURATION AFTER ATTACK BY 9-SEC, 9-FT WAVES
SHORELINE CONFIGURATION AFTER ATTACK BY 11-SEC, 7-FT WAVES
SHORELINE CONFIGURATION AFTER ATTACK BY 13-SEC, 9-FT WAVES
SHORELINE CONFIGURATION AFTER ATTACK BY 15-SEC, 7-FT WAVES
SHORELINE CONFIGURATION AFTER ATTACK BY 15-SEC, 12-FT WAVES
EL 0.0 FT
EAST JETTY
N
SCALES
MODEL 4 0 4 8 FT
PROTOTYPE 300 0 300 600 FT

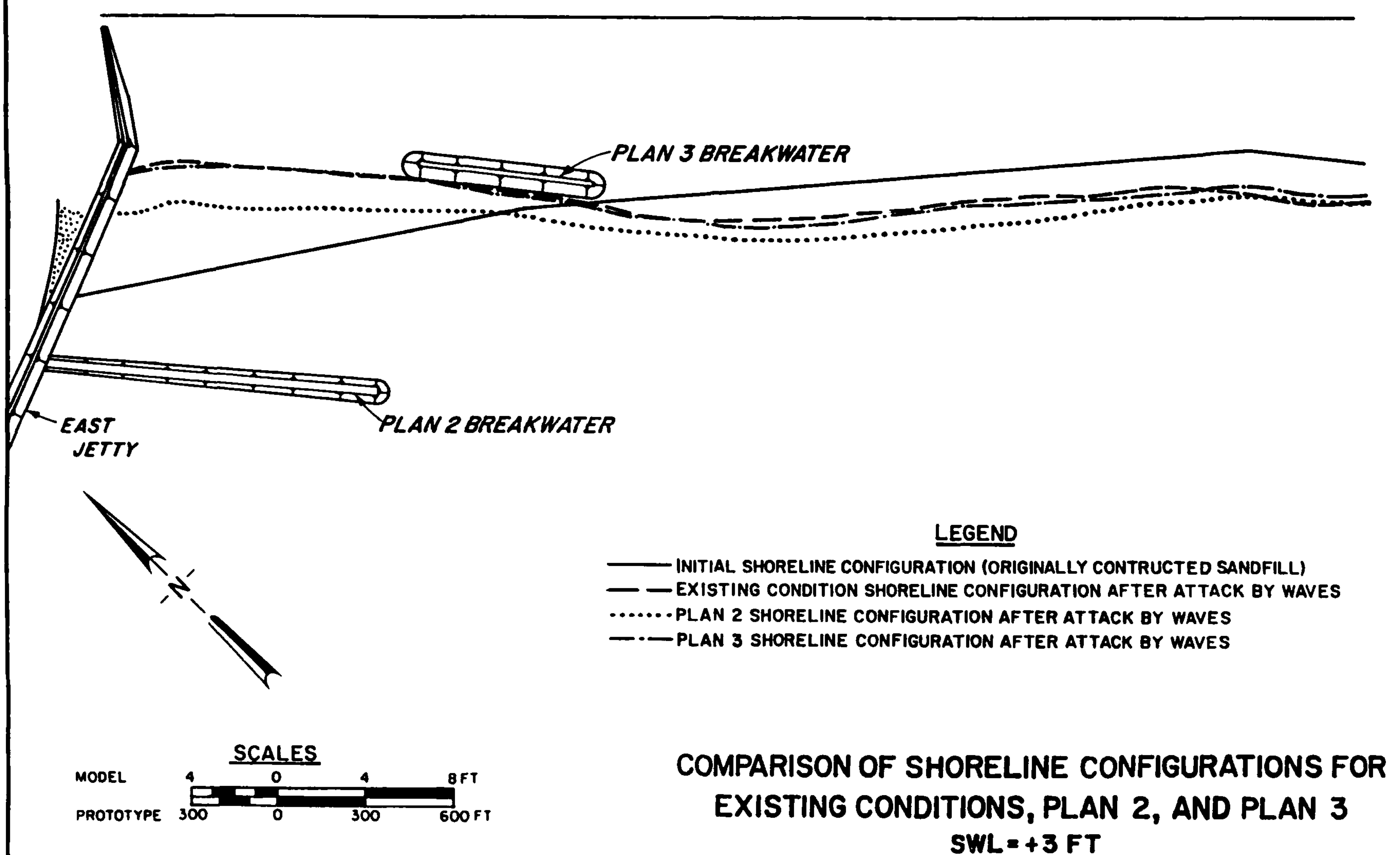


SHORELINE EROSION AND ACCRETION
PLAN 3, SWL = +3 FT



COMPARISON OF SHORELINE CONFIGURATIONS FOR EXISTING CONDITIONS AND PLAN I

SWL = +7 FT



COMPARISON OF SHORELINE CONFIGURATIONS FOR EXISTING CONDITIONS, PLAN 2, AND PLAN 3

SWL = +3 FT